JUL 17 19

Volume 17 JULY, 1933 Number 7

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS

East Texas Oil Field *By H. E. Minor and Marcus A. Hanna* 757

Distribution of Oil Pools in Kansas in Relation to Pre-Mississippian Structure and Areal Geology *By John L. Rich* 793

Driscoll Pool, Duval County, Texas *By I. R. Sheldon* 816

Preservation of Oil During Erosion of Reservoir Rocks *By George Edwin Dorsey* 827

GEOLOGICAL NOTES

Classification and Nomenclature of Rock Units 843

Permian Algal Reef in South Park, Colorado *J. Harlan Johnson* 863

Overturned Beds in Arbuckle Mountains, Oklahoma *Robert H. Dott* 865

DISCUSSION

Review of Tertiary Stratigraphy of Louisiana *Hugh D. Miser, chairman, Committee on Geologic Names* 869

Alexander Deussen 871

REVIEWS AND NEW PUBLICATIONS

Recent Publications 872

THE ASSOCIATION ROUND TABLE

Association Committees 874

AT HOME AND ABROAD

Current News and Personal Items of the Profession 875

COPYRIGHT, 1933, BY THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

Prestige

Means "Approval By Many Men"

WHEN many men have found satisfaction in the use of a tool and have given it their "approval," the tool has "prestige."

When a man or a company of men has performed so well in the past that you can confidently expect the same good performance in the future, that man or company has "prestige."

"Buying on prestige" is safe. You are using the judgment of many in the absence of personal experience.

You can safely buy the Baker Cable Tool Core Barrel on prestige because it has satisfied Operators, Engineers and Geologists all over the world.

Or . . . if you have experienced satisfactory service with *other* Baker equipment, you are safe in expecting satisfactory service with the Baker Core Barrel.

You can confidently expect "perfect cores" easily and surely . . . a tool any cable tool driller can use . . . economy in first costs and use . . . and RESULTS—an accurate log of the well, completely or for any part you desire.

Interesting literature is available. Simply ask for Catalog on the Baker Cable Tool Core Barrel.

BAKER OIL TOOLS, INC.

HUNTINGTON PARK, CALIFORNIA

COALINGA · TAFT · HOUSTON · OKLAHOMA CITY · TULSA · NEW YORK

Please use coupon on last page of advertisements in answering advertisers

Volume 17 Number 7

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JULY 1933

EAST TEXAS OIL FIELD[1]

H. E. MINOR[2] and MARCUS A. HANNA[2]
Houston, Texas

ABSTRACT

The East Texas field, as the name implies, is located in the extreme eastern part of Texas. The discovery of this field was made on October 3, 1930, by C. M. Joiner *et al.* The field has produced 234 million barrels of oil to January 1, 1933. At the present time (January 1, 1933) the field is restricted to a flow of 28 barrels per day per well. There were approximately 9,600 producing wells on January 1, 1933. Estimates of the total production vary from 1 billion to 2 billion barrels. The actual potential production of this field is estimated to vary from 2 million to 4 million barrels per day. A total ranging from 10,000 to 12,000 wells will probably be drilled, representing a total drilling investment of $250,000,000 to $300,000,000. The field comprises approximately 110,000 acres, and covers portions of Rusk, Cherokee, Smith, Gregg, and Upshur counties. The production is derived from sand members of the Eagle Ford-Woodbine group, of Cretaceous age. The structure of the reservoir is a broad, westward dipping, truncated homocline.

INTRODUCTION

The East Texas oil field comprises approximately 110,000 acres, covers portions of four counties, and has produced under restricted flow over 234 million barrels of oil to January 1, 1933.

An attempt to forecast the future productive possibilities of a field of this magnitude at such an early date in its development is difficult and hazardous.

The manner in which this major field of multi-ownership is being developed and extended is a decided deviation from past methods of field development.

[1] Read before the Association at the Oklahoma City meeting, March 24, 1932. Manuscript received, April 21, 1933. Published with permission of the Gulf Production Company.

[2] Geological department, Gulf Production Company.

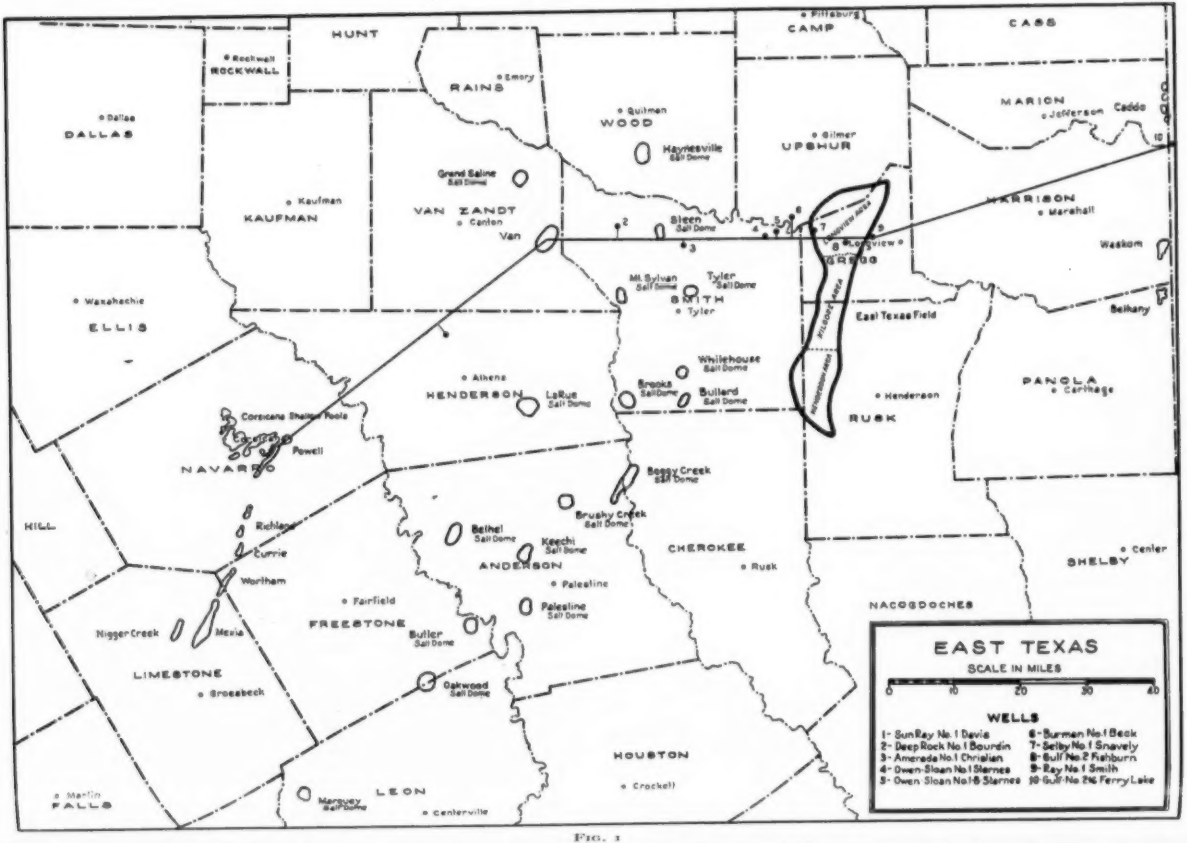
HUNT
CAMP
CASS
ROCKWALL
Rockwall
Pittsburg
RAINS
Emory
MARION
Jefferson
Caddo
DALLAS
Dallas
WOOD
Quitman
Hawkinsville Salt Dome
UPSHUR
Gilmer
KAUFMAN
Kaufman
VAN ZANDT
Canton
Grand Saline Salt Dome
Sligo Salt Dome
HARRISON
Marshall
Longview
Waskom
Van
Mt. Sylvan Salt Dome
Tyler Salt Dome
SMITH
Tyler
Waxahachie
ELLIS
East Texas Field
Belhany
Whitehouse Salt Dome
Athens
HENDERSON
LaRue Salt Dome
Brooks Salt Dome
Bullard Salt Dome
PANOLA
Carthage
Henderson
RUSK
Corsicana Shallow Pools
Powell
NAVARRO
Bessy Creek Salt Dome
HILL
Richland
Currie
Bethel Salt Dome
Brushy Creek Salt Dome
Keechi Salt Dome
ANDERSON
CHEROKEE
Rusk
Center
SHELBY
Wortham
Fairfield
Palestine
Palestine Salt Dome
NACOGDOCHES
Nigger Creek
Mexia
FREESTONE
Butler Salt Dome
LIMESTONE
Groesbeck
Oakwood Salt Dome
HOUSTON
Crockett
Marlin
FALLS
Mercury Salt Dome
LEON
Centerville
EAST TEXAS
SCALE IN MILES
0 10 20 30 40
WELLS
1- SunRay No. 1 Davis
2- Deep Rock No. 1 Bourdin
3- Amerada No. 1 Chrisian
4- Owen-Sloan No. 1 Starnes
5- Owen-Sloan No. 6 Starnes
6- Burmen No. 1 Beck
7- Selby No. 1 Snavely
8- Gulf No. 2 Fishburn
9- Ray No. 1 Smith
10- Gulf No. 216 Ferry Lake

FIG. 1

Acknowledgments

The writers express their appreciation to W. B. Milton[3] for assistance in preparation of manuscript, to J. S. Woods[3] and B. E. Carson[3] for drafting, and to Herbert Oliver[3] for stenographic work.

Location

The location of the oil fields and the salt domes of the East Texas basin is shown in the sketch map (Fig. 1).

The East Texas field has a length of 39 miles and an average width of 4½ miles. Its area of 172 square miles is situated in the several counties, by acres, approximately as follows: 44,096 in Rusk, 220 in Cherokee, 3,123 in Smith, 54,500 in Gregg, and 8,448 acres in Upshur County.

On account of the sequence of discoveries and the magnitude of the field, three separate districts are recognized and are known as the Henderson, Kilgore, and Longview or Gladewater districts.

The Henderson district comprises that part of the field in Rusk, Cherokee, and Smith counties north to a line extending east from Overton.

The Kilgore district is joined on the south by the Henderson district and includes that area in Rusk and Gregg counties with its northern boundary being determined by Sabine River.

The Longview district includes the remainder of the field in Gregg and Upshur counties north of Sabine River.

The nearest producing fields are: the Boggy Creek field, 27 miles southwest, in Anderson and Cherokee counties, Texas; the Van field, 40 miles west in Van Zandt County, Texas; and the Caddo field, 50 miles east in Caddo Parish, Louisiana.

History

The exploration of C. M. Joiner, discoverer of the East Texas field, began in August, 1927, when his first location was made for Bradford No. 1 in the Juan Ximines Survey in Rusk County. In the drilling of the first test, numerous difficulties were experienced, many of which were attributed to inferior equipment. After 6 months' effort this hole was junked and the test abandoned at a depth of 1,098 feet.

At this time, financial difficulties (so common to the majority of wildcatters) confronted Joiner and it was not until April, 1928, that he was successful in locating and spudding his second well, Bradford No. 2. This location was made 100 feet northwest of Bradford No. 1

[3] Geological department, Gulf Production Company, Houston, Texas.

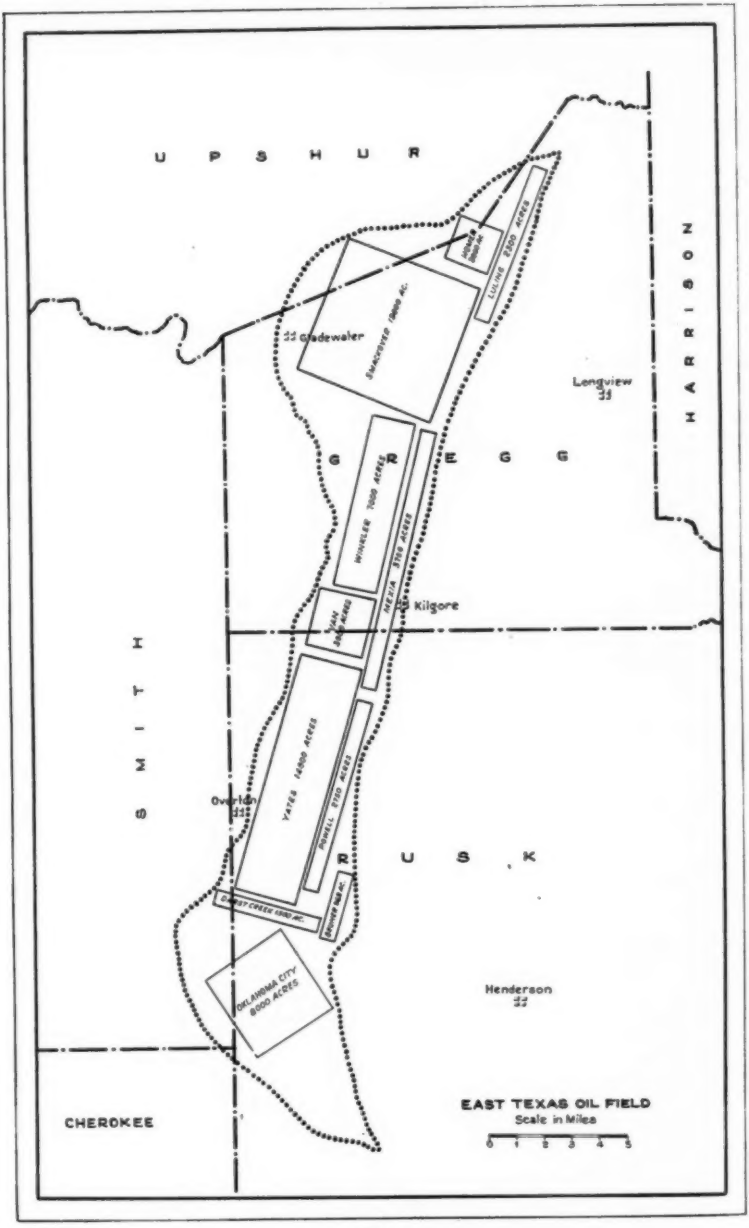
U P S H U R
HARRISON
G R E G G
S M I T H
R U S K
CHEROKEE
Longview
Kilgore
Henderson
Overton
Gladewater
YATES 14000 ACRES
EAST TEXAS OIL FIELD
Scale in Miles
0 1 2 3 4 5

FIG. 2

and 11 months of intermittent drilling were required to reach a depth of 2,518 feet, at which depth, this well, like its predecessor, was junked and abandoned. However, before the abandonment of the hole an attempt was made without success to test a showing of oil at the shallower depth of 1,437–1,460 feet.

With unlimited faith in his prospect, and determined that he would make a fair test of the area, Joiner sacrificed much of his original 10,000-acre block in order to finance the third well. Partially successful in raising funds, he located Bradford No. 3 only 300 feet south of his original well and in January, 1930, the well had reached a depth of 1,530 feet and was shut down. Operations were resumed on this test in the spring of 1930. The funds of Joiner *et al.* had shrunk to such an extent that it became necessary to fire the boilers with wood taken from the lease, and in many cases stock was given in return for labor and supplies. A showing of oil was encountered at 3,592 feet and in order to secure casing from one of the supply companies, a drill-stem test was required. The test was made and the well showed considerable amounts of oil and gas. Casing was secured on the strength of the favorable test. The reward for perseverance and determination came to Joiner on October 3, 1930, when Joiner *et al.* Daisy Bradford No. 3 was completed as a 300-barrel well at a depth of 3,592 feet.

After the completion of the Joiner well, other discoveries followed in rapid succession. Many of the subsequent wells were so far removed from the original discovery that the majority of the oil fraternity were bewildered as to whether a single pool or three separate pools had been found. It began to appear as though an oil well had become the rule and a dry hole the exception in this new oil territory, which seemed to have no limits.

The first extension to the Joiner area was that of the Deep Rock Oil Company on the Ashby 75-acre tract, located 1 mile west. This well was completed December 4, 1930, with an initial flow of 3,000 barrels. Ten miles northwest the Bateman Crim No. 1, in the E. G. Sevier Survey in Rusk County, was being drilled and on December 28, 1930, this well was brought in, flowing 10,000 barrels per day from a depth of 3,652 feet. The next extension to the field was the Farrell and Moncrief Lathrop No. 1, 15 miles north and slightly east of the Bateman Crim No. 1. This well came in, January 26, 1931, making 500 barrels per hour from a total depth of 3,587 feet.

At this stage of development in the East Texas field there were four wells completed: one, 1 mile west; another, 10 miles north; and still another, 25 miles north of the original discovery well. Surface structure had failed to aid in the solution of the problem; conse-

quently, the intelligent buying of acreage at this time had to be based on what meager surface and subsurface information the individual or company had at hand. It was not until the gaps were finally closed that the magnitude of this gigantic pool was fully realized. The areal magnitude of the field is made more impressive by the graphic comparison with other large fields as shown in Figure 2.

Stratigraphy

Regional geology

The East Texas oil field lies within the broad belt of Cretaceous and Tertiary rocks which border the Gulf of Mexico and unconformably overlap the pre-Cretaceous rocks of the interior. No wells in the immediate vicinity of the field have penetrated to the unconformity between the Cretaceous and pre-Cretaceous, although the contact is exposed at the surface less than 100 miles north. The areal geology of the immediate area is well shown on the recent United States Geological Survey map of Texas.[4] The contact relationship of the Cretaceous and pre-Cretaceous is well shown on the United States Geological Survey map of Oklahoma[5] and Arkansas.[6] Moody's[7] map of 1931 shows the areal geology of Louisiana and Mississippi and adjacent states.

Major regional tectonics

The subject of structural movement is too broad to be discussed in detail in this paper. Only the fundamentals involved in the formation of the East Texas structure are considered.

The major regional tectonic features of the East Texas and adjacent west Louisiana area consist of a southward and eastward dipping homocline of Cretaceous and Tertiary rocks extending as an arc through the counties including Bowie, Delta, Hunt, Kaufman, and southward beyond Limestone. This southward and eastward dipping homocline is broken with strike faults, such as those of the Powell-Mexia district. Within the homocline are such major features as the Van structure and the Athens flexure. This homocline descends south and east into the East Texas geosyncline which extends in general north and south through Smith, Anderson, and Cherokee

[4] *U. S. Geol. Survey Geol. Map of Texas;* 1: 500,000. Preliminary edition 1932. Final edition in press.

[5] *U. S. Geol. Survey Geol. Map of Oklahoma;* 1: 500,000 (1926).

[6] *U. S. Geol. Survey Geol. Map of Arkansas;* 1: 500,000 (1929).

[7] C. L. Moody, "Tertiary History of Region of Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), map opp. p. 534.

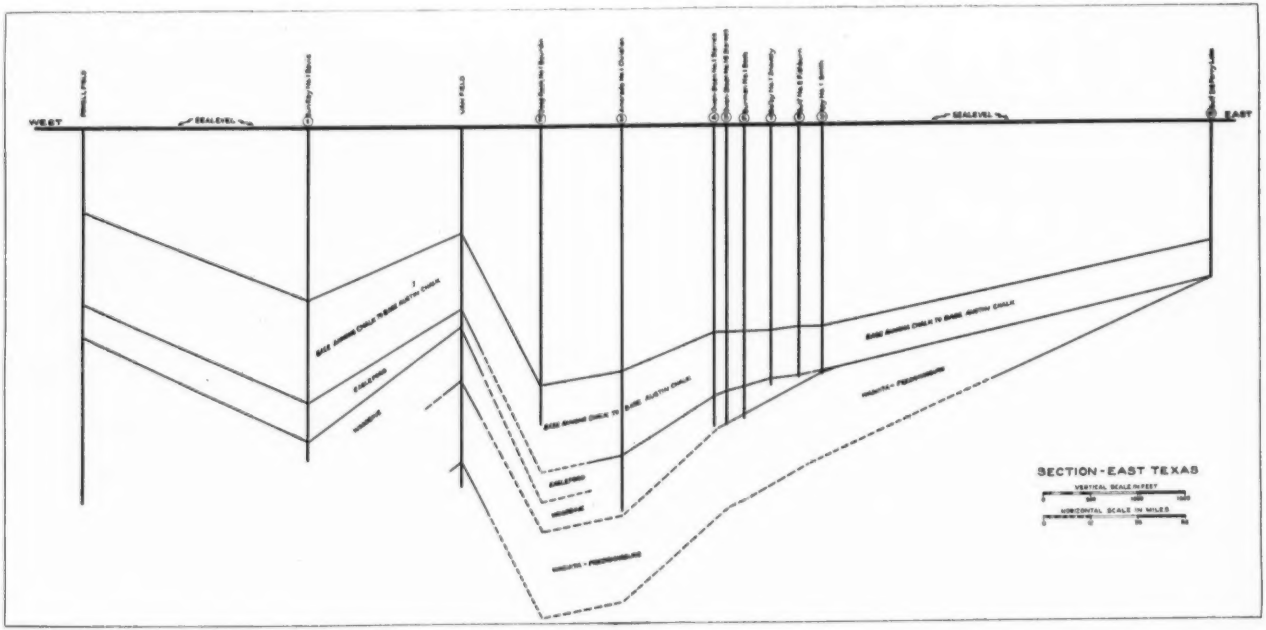
WEST
SEALEVEL
SEALEVEL
EAST
SECTION - EAST TEXAS
VERTICAL SCALE IN FEET
HORIZONTAL SCALE IN MILES

FIG. 3

counties. At its northward end, the geosyncline passes east around the north side of the Sabine uplift. From Smith County, Texas, the formations rise east, culminating in the Sabine uplift of eastern Texas and western Louisiana. The general character of the homoclines on either side of the East Texas geosyncline is shown on Plummer's Woodbine map.[8] Moody[9] has discussed the general character and history of the Sabine uplift.

The East Texas field lies on the westward dipping homocline between the Sabine uplift and the East Texas geosyncline. In general, the closure of the East Texas field against the Sabine uplift is due to the unconformable overlap of the Austin chalk across the Eagle Ford-Woodbine section onto the Washita. In detail, as discussed later, the closure is somewhat more complicated than this.

Section *AB* indicated in Figure 1 represents a cross section (Fig. 3) of the East Texas basin, constructed from well logs, and extends from Ferry Lake, Louisiana, on the east, to the Powell field in Limestone County, Texas, on the west.

Formations within East Texas Field

Claiborne group

Figure 4 shows graphically the formations encountered in wells drilled within the East Texas field. Due to the fact that the lithological units within these formations are lenticular, the section of Figure 4 is idealized. Depending on the location of wells within the field and the variation in elevation, the thickness of Claiborne drilled is variable. With the exception of the Eagle Ford-Woodbine section, the remainder of the formations within the field are more or less constant in thickness.

Only the lower members of the Claiborne group are present within the area of the East Texas field. With the possible exception of a few outcrops of the Weches in the northern and northwestern section of the field, only the two lower members of the Claiborne are present: the Queen City above and the Reklaw below.

The Queen City is predominantly a sand member. Wendlandt and Knebel[10] stated,

> The Queen City consists of local clay zones, zones of sandy clay, beds of almost pure, cross-bedded, light-colored quartz sand, thin beds of lignite, and possibly two local beds of bentonitic clay.

[8] F. B. Plummer and C. E. Sargent, *Univ. Texas Bur. Econ. Geol. Map of Northeast Texas* (1931). Contours in Woodbine area drawn on top of sand.

[9] C. L. Moody, *op. cit.*

[10] E. A. Wendlandt and G. Moses Knebel, "Lower Claiborne of East Texas, with Special Reference to Mount Sylvan Dome and Salt Movements," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), p. 1355.

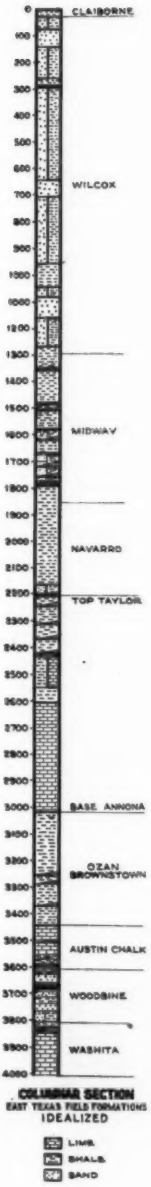
0
CLAIBORNE
100
200
300
400
500
600
700
WILCOX
800
900
1000
1100
1200
1300
1400
1500
1600
MIDWAY
1700
1800
1900
2000
NAVARRO
2100
2200
TOP TAYLOR
2300
2400
2500
2600
2700
2800
2900
3000
BASE ANNONA
3100
3200
OZAN
BROWNSTOWN
3300
3400
3500
AUSTIN CHALK
3600
3700
WOODBINE
3800
3900
WASHITA
4000
COLUMNAR SECTION
EAST TEXAS FIELD FORMATIONS
IDEALIZED
LIME
SHALE
SAND

FIG. 4

About two-thirds of the way down in the Queen City section are the green sand Omen beds.

The Reklaw, basal member of the Claiborne, consists chiefly of green sands and glauconitic clays.

Wendlandt and Knebel[11] gave the thickness of the Queen City within the East Texas basin as varying from 0 to 480 feet, and the thickness of the Reklaw as varying from 30 to 130 feet.

Both the Omen beds and the Reklaw were used for control in making near-surface structural contour maps within the general area of the East Texas field.

WILCOX GROUP

In the idealized columnar section as found in the East Texas field (Fig. 4) approximately 1,300 feet of beds have been assigned to the Wilcox group. The Wilcox group consists of massive beds of sand which are in many places highly cross-bedded, sandy shales or clays, beds of shales or clays, lignitic clays, lignites, and beds of white kaolinitic clay. For the most part the beds of the Wilcox group are non-marine.

In this article the sand zone commonly found at the base of the Claiborne or the top of the Wilcox, usually referred to as the Carrizo, has been included in the Wilcox group. It is placed by many at the base of the Claiborne. Since sufficient evidence has not been presented definitely to place it in one or the other, it is allowed to remain in the Wilcox in this article.

MIDWAY GROUP

The Midway group within this area is usually considered the basal group of beds of the Tertiary. The beds consist of shales, sandy shales, sandy and shaly limestones, and beds of glauconitic sands and shales. For the most part it is sufficiently marine to allow definite recognition on the basis of fossils. In the idealized section, 500–550 feet of beds have been assigned to the Midway group.

NAVARRO FORMATION

In general, the Navarro formation consists of dark shales and sandy shales. At the base, in many places, is found a sand and sandy shale zone which can be considered approximately the equivalent of the Nacatoch sand zone of Arkansas. In the idealized section, approximately 350 feet of beds have been assigned to the Navarro formation.

[11] E. A. Wendlandt and G. Moses Knebel, *op. cit.*, p. 1371.

UPPER CHALK GROUP

Controversy exists as to what constitutes the base of the Navarro formation and the top of the Taylor formation. In this article the top of the Taylor is placed at the top of the upper chalk. This contact is approximately the equivalent of the top of the Saratoga of the Arkansas section. The base of the upper chalk is approximately the equivalent of the base of the Annona of the Arkansas section. It has not been found convenient to separate the upper chalk into the Saratoga-Marlbrook-Annona members, although there is variation in the shale-chalk character within the unit. In general, the upper chalk consists of shale, chalk and chalky shale in the upper part, whereas the lower portion consists chiefly of chalk with lesser amounts of shale and shaly chalk. In the idealized section, 800 feet has been assigned to the upper chalk member (top Taylor to base of Annona).

OZAN-BROWNSTOWN

The beds found between the base of the Annona and the top of the Austin chalk are termed Ozan-Brownstown in this article. The Ozan-Brownstown within the East Texas field consists of shales, thin lenses of sand, and sandy shales, together with a few chalky or limy shales. In the idealized section, approximately 425 feet of beds have been assigned to the Ozan-Brownstown.

AUSTIN CHALK

The Austin chalk, as shown in the idealized section, consists of hard chalk with minor amounts of chalky shale and shale. The lower few feet are conglomeratic, with the pebbles and boulders composed of various types of material of pre-chalk age. As indicated in the idealized section, the Austin chalk has been taken as a lithologic unit rather than a faunal unit. The correlative of the top of the Austin chalk of the type locality probably lies considerably above the top as given in the idealized section, making the idealized section Austin chalk approximately the equivalent of the Ector tongue as found in the northwestern part of the basin. In the idealized section, approximately 125–150 feet of material has been assigned to the Austin chalk.

EAGLE FORD-WOODBINE GROUP

GENERAL STATEMENT

The Eagle Ford-Woodbine group is the producing horizon of the East Texas field. Lithologically the group is composed of black fissile shales, gray and greenish shales, mottled or red-bed shales, sandy

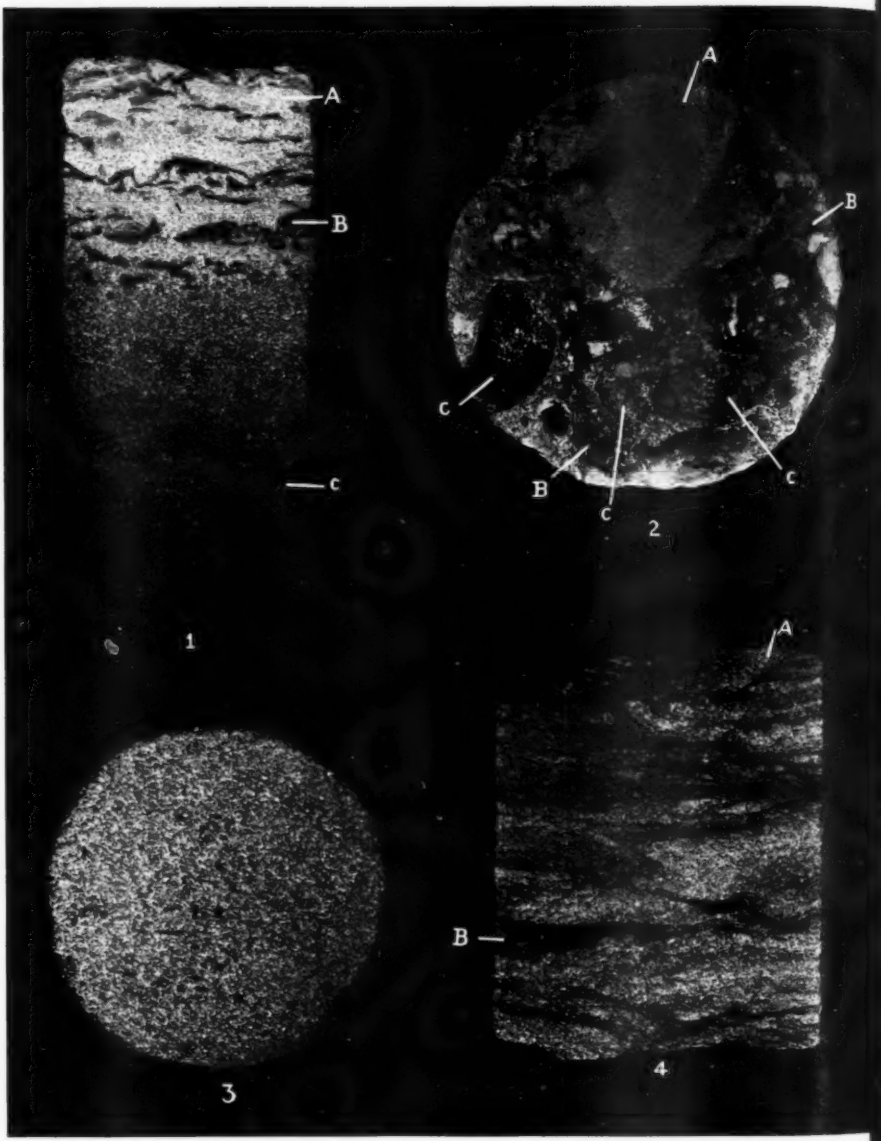

PLATE 1

FIG. 1.—Core showing differential saturation. Gulf Production Company's Brightwell No. 5, Kilgore di trict, Rusk County. Depth, 3,629–35 feet. *A*—Sand with only trace of saturation. *B*—Dark silty shale. *C*—Exc lently saturated sand. Magnification, 0.78 ×.

FIG. 2.—Core of conglomeratic sand with clay matrix. In this type, sand is bound with clay rather than s as in Figure 2, Plate 2. Gulf Production Company's Spear No. 7, Kilgore district, Gregg County. Depth, 3,537- feet. *A*—Large sand pebble. *B*—Dense clay matrix. *C*—Rock pebbles. Slight oil stains in more porous sand area Porosity, 6.29 per cent. Magnification, 1.2 ×.

FIG. 3.—Core of excellently saturated sand. Gulf Production Company's Brightwell No. 5, Kilgore distri Rusk County. Depth, 3,629–35 feet. Core leached of oil before photograph was taken. This saturated sand w thin zone in non-saturated silty sand and silty clay zone. Magnification, 1.2 ×.

FIG. 4.—Irregularly laminated silty sand. Gulf Production Company's Fonville No. 2, Longview distri Gregg County. Depth, 3,504–13 feet. *A*—More sandy part. *B*—More silty part. No saturation. Porosity, 1 per cent. Magnification, 1.2 ×. (See No. 7, Fig. 5.)

shales, shaly and silty sands, homogeneous and saccharoidal and cross-bedded sands, as well as silty and sandy conglomerates. Due to the predominantly non-marine character of the beds, a multiplicity of disconformities, cross-bedding, and channeling existed at the time of deposition. In consequence, the beds are variable both horizontally and vertically. In general, the group is heterogenous and clastic. Little calcareous material other than secondary cement is found within these beds.

LITHOLOGICAL CHARACTERISTICS

Shales.—Shales of several types are present. Black fissile shales have been cored in several of the wells, particularly in the northwestern section of the field. Few fossils have been found within them. Megascopically they suggest the fissile Eagle Ford shales of the west side of the basin, but microscopically they differ in several respects. It is possible that some of these black fissile shales may grade westward into the typical Eagle Ford of the west side of the basin. Stratigraphically they occur in the upper part of the Eagle Ford-Woodbine group along the western and northwestern side of the field. The dark shales along the eastern part of the field and at the base of the sand section lie stratigraphically below the shales previously mentioned and many of them contain Washita fossils. They are not to be confused with the black fissile shales which occur higher in the section.

Gray and greenish shales are present in many of the wells. The gray shales are largely of clastic origin, being at the fine end of the sand-shale series of sediments. Many of the greenish shales, on the other hand, have the appearance of waxy bentonites. Neither of these shales was detailed petrographically.

Red-bed shales are common. Most of them are mottled with shales of gray, green, violet, red, and brown. Many cores have been noted, however, in which one of these colors predominated or existed throughout.

Silts.—Well sorted silts (0.05 to 0.005 millimeter) are not common within the East Texas field. Finer or coarser material is almost invariably present.

Sands and conglomerates.—Sandstones and conglomerates are the reservoir rocks of this field. Considerable variation exists between the different sand lenses within this group of beds.

The photograph (Plate 1, Fig. 4) and the corresponding sand analysis (Fig. 5, No. 7) illustrate one type of silty sand found in the field. The material is irregularly banded with dark, shaly silt, as at *B* in the photograph. The lighter areas of the core are silty rather than shaly sand. The silt is light-colored, finely granular, lime-free material.

Unfortunately, time has not been available for a detailed petrographical study of the silty material of these cores. Such silty sands are usually referred to as ashy or trashy sands. In part, the material may be altered ash, although in certain instances it is of secondary origin, possibly transported and precipitated from circulating waters which have been in contact with altering ash beds. When the silt is removed from these silty sands by sieving, the more sandy material consists of

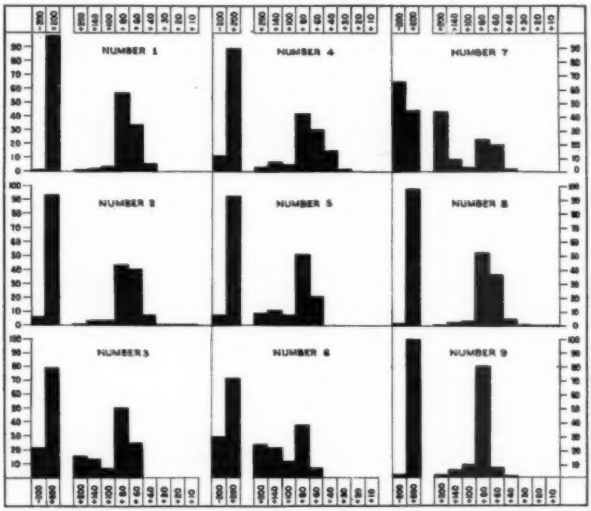

FIG. 5.—First column shows percentage of material by weight which passed through 200-mesh sieve. Second column shows percentage of material by weight retained on 200-mesh sieve. Third column shows percentage of material by volume caught on 200-mesh sieve but which had passed through 140-mesh sieve, et cetera.

No. 1. Core from Gulf Production Company's Murphy No. 2, Henderson district, Rusk County. Depth, 3,774–78A. Excellent saturation. Porosity, 27.2 per cent. Largest porosity found in sands examined from East Texas field.

No. 2. Core from same well as No. 1. Depth, 3,774–78C. Fair saturation. Porosity, 17.55 per cent.

No. 3. Core from same well as No. 1. Depth, 3,774–78D. Poor saturation. Porosity, 11.0 per cent.

No. 4. Core from same well as No. 1. Depth, 3,778–80. Good saturation. Porosity, 19.66 per cent.

No. 5. Core from same well as No. 1. Depth, 3,785–86. Fair saturation.

No. 6. Core from same well as No. 1. Depth, 3,785–86A. Slight saturation. Porosity, 11.0 per cent.

No. 7. Core from Gulf Production Company's Fonville, No. 2, Longview district, Gregg County. Depth, 3,405–13. No saturation. Porosity, 17.5 per cent. (See Plate 1, Fig. 4.)

No. 8. Core from same well as No. 7. Depth, 3,555–56. Excellent saturation.

No. 9. Core from Gulf Production Company's Brightwell No. 5, Kilgore district, Rusk County. Depth, 3,635–41. Excellent saturation. (See Plate 2, Fig. 4.)

subangular grains of various sizes as shown in the analyses of Figure 5. The individual grains are predominantly of quartz. Feldspars are not uncommon. Pink orthoclase is generally more abundant in the lenses in which material as large as small gravel is present. In the samples examined there has been only a small proportion of heavy minerals.

It has been interesting to note the variation in oil saturation in respect to silt percentage. The core shown in Plate 1, Figure 4, and sand analysis (Fig. 5, No. 7), had a porosity of 17.5 per cent, yet showed no oil in any of the common solvents. This might be due to presence of water or saturation with gas. The former appears to be the fact, since a sufficient amount of water circulated through this sand after deposition to allow precipitation of siliceous cement, and it is commonly stated that all gas within this field was in solution at the time the field was discovered. Although this silty sand had a porosity higher than other saturated sands, the water was not displaced by oil. When this core was dried and placed in East Texas crude, it very quickly became saturated with oil. Differential saturation in silty sand cores has been observed in many other East Texas cores. The photographs of Plate 1, Figure 1, and Plate 2, Figure 1, show marked difference in the degree of saturation in cores with variation in silt percentage.

The best reservoir sands of the field are shown in the photographs (Plate 1, Fig. 1 at *C*, Plate 1, Fig. 3, and Plate 2, Fig. 4). They are more or less homogeneous in megascopic aspect and saccharoidal in texture. The percentage of material finer than 200 mesh is shown in the sand analyses of Figure 5. When freed of oil they are light in color and are composed predominantly of quartz. Heavy minerals are not abundant. The presence or absence of ashy material apparently depends on the position of the sand lens within the columnar section. The majority of grains vary in size between 0.1 and 0.25 millimeter.

Some of the sands from wells adjacent to the field are green, suggesting glauconite. On close examination, however, the green material is found to be only a thin coating over the grains and not of sufficient amount to appreciably change the porosity. It is very probable that some sands of this character are present in the northern part of the field, although none has been observed by the writers.

The conglomerates of the field can be readily separated into two groups. First, the conglomerate at the base of the Austin chalk (Plate 2, Fig. 3) which consists of pre-Austin chalk sand and pebbles of various types and ages imbedded in a chalk matrix containing Austin chalk fossils. The pebbles of the chalk conglomerate are much the same as those of the second type of conglomerate. The second type of

conglomerate is the sand conglomerate found within the Eagle Ford-Woodbine group. The photograph (Plate 2, Fig. 2) shows one of these conglomerates. The area, *A*, shows soft, white, chalk-like, lime-free pebbles which in thin sections are similar to the phonolite and ash pellets figured by Ross, Miser and Stephenson.[12] Thin sections were not made of the rock pebbles shown at *B*. Some fine ashy material was found as a part of the matrix in this core. Plate 1, Figure 2, shows another type of these conglomerates. In this core the matrix is a dense clay. Ashy and rock pebbles are present as well as a large sand pebble. Pink orthoclase was common in this core. Other variations are present in these intra-group conglomerates, but these will suffice to indicate their general character.

CEMENTATION

Secondary cementation is a dominant characteristic of the silts, sands, and conglomerates of this group of beds. No sample has been examined by the writers from the East Texas field in which secondary siliceous cement was not present. Even those cores which were found as loose sand in the core barrel contain secondary cement. Many of the grains have new faces developed. One reason the more permeable sands form an ideal reservoir is that the individual grains are held rigid by the small amount of this siliceous cement. The loose sand cores are not due to the sand in place being loose, but rather to the method of coring.

Secondary calcareous cementation is common within the silts, sands, and conglomerates of this group of beds. Many cores have been examined in which no porosity could be found. The cement was preponderantly calcium carbonate. It was interesting to note that the precipitation of this calcareous cement occurred after siliceous cement, since the sand grains were firmly held together by siliceous cement after calcareous cement was removed with hydrochloric acid. Many wells have been finished without even setting perforated pipe. As far as the writers are aware the cementation has been sufficient to prevent these wells from making sand.

THICKNESS

The thickness of the Eagle Ford-Woodbine group ranges from almost zero on the east side of the field to possibly 1,000 feet in the center of the East Texas basin.

[12] Clarence S. Ross, Hugh D. Miser, and Lloyd W. Stephenson, "Water-Laid Volcanic Rocks of Early Upper Cretaceous Age in Southwestern Arkansas, Southeastern Oklahoma, and Northeastern Texas," *U. S. Geol. Survey Prof. Paper 154* (1928), Pl. 21, Fig. B; Pl. 22, Fig. A.

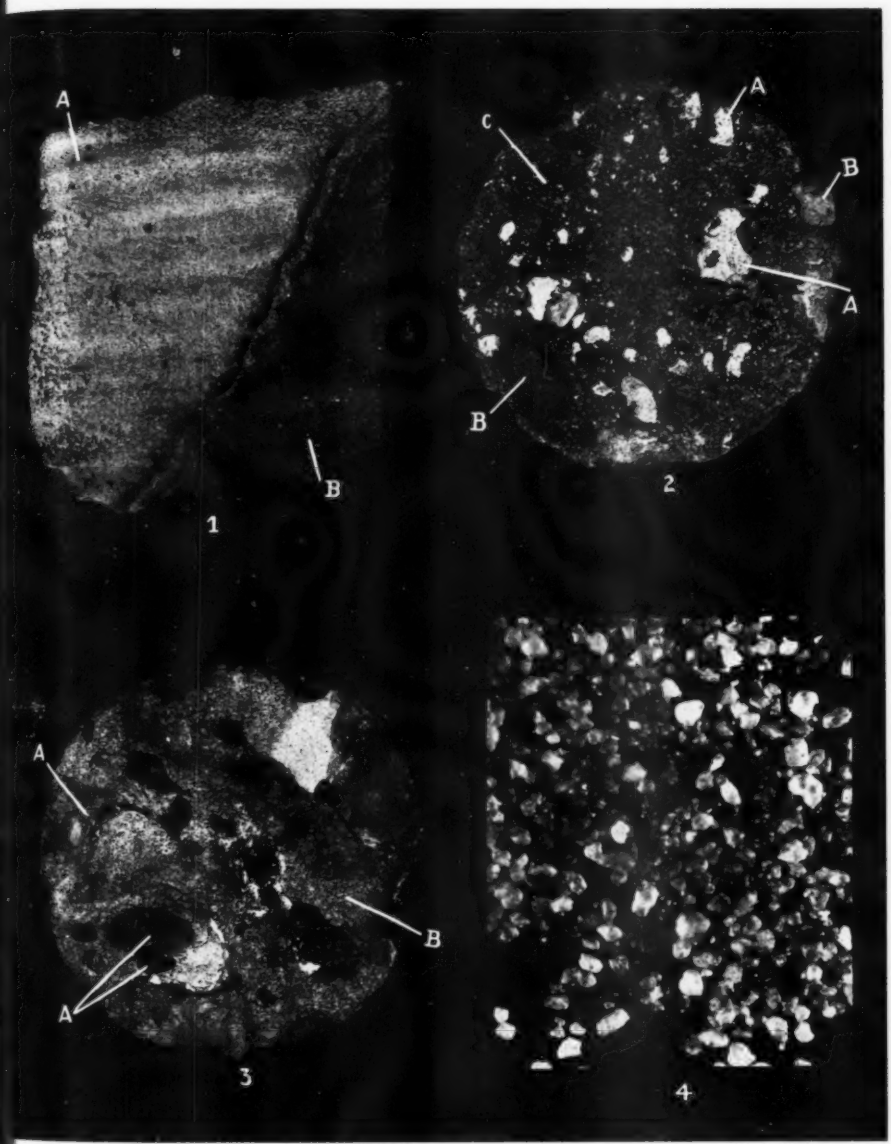

PLATE 2

FIG. 1.—Core showing slight dislocation and with differential saturation. Gulf Production Company's Brightwell No. 5, Kilgore district, Rusk County. Depth, 3,623–29 feet. *A*—Silty sand with no saturation. *B*—Porous sand with saturation. Magnification, 1.2 ×.

FIG. 2.—Conglomeratic sand. Gulf Production Company's Alexander No. 1, Kilgore district, Gregg County. Depth, 3,522 feet. *A*—Soft white pebbles. *B*—Rock pebbles. *C*—Porous sand. Differential saturation. Porosity, 7.65 per cent. Magnification, 1 ×.

FIG. 3.—Chalk conglomerate. Gulf Production Company's Spear No. 7, Kilgore district, Gregg County. Depth, 3,537–46 feet. *A*—Rock pebbles. *B*—Sandy chalk. No saturation. Porosity, 5.45 per cent. Magnification 1.2 ×.

FIG. 4.—Excellently saturated sand. Gulf Production Company's Fonville No. 2, Longview district, Gregg County. Depth, 3,555–56 feet. (See No. 8, Fig. 5.)

STRUCTURE, AGE, AND CORRELATION

The age and correlative equivalents of the Eagle Ford-Woodbine group of the East Texas field have been moot questions since the discovery of the field. Even to-day unanimity does not exist. The reason for the disagreement is the paucity of fossils within the group. The thesis of this paper is not the settlement of this controversial subject. It will be discussed only in so far as it pertains to the structure of the immediate field.

As indicated in Figure 3, the field lies on the west slope of the Sabine uplift. (In this paper the western slope of the Sabine uplift is considered as terminating on its western side at the axis of the East Texas geosyncline.) The up-dip closure of the field is due to the unconformable overlap of the Austin chalk across the bevelled edge of the Eagle Ford-Woodbine group and onto the underlying Washita group. Many hypotheses have been advanced to explain the wedge-like structure of the East Texas field but, to the writers, the most feasible hypothesis is that periodic structural movements, followed by truncation and overlap, were responsible for the enormous accumulation of oil in this mammoth pool.[13,14] True, the unconformities may be of limited areal extent, but they are unconformities of sufficient local magnitude to cause the structural conditions existing in this field.

The Eagle Ford-Woodbine group of beds was described in considerable detail by Hill.[15] In his discussion he continued the use of the term, Dexter sands, for the lower sand zone, and introduced the term, Lewisville beds, for the upper brackish-water phases. He placed the Eagle Ford above the Lewisville beds. The clay zone lying at the base of the Dexter sand is discussed but not named. He considered the break between the Lower and Upper Cretaceous to be at the base of the clay member below the Dexter sand.

The threefold division (basal clay, a lower and an upper sand member) has continued in use. Scott[16,17] was the first to consider the lower clay and the lower sand as the depositional product of a regression. This conception was discussed again by both Scott and Plummer[18]

[13] A. I. Levorsen, *International Petrol. Tech.*, Vol. 8 (June, 1931), pp. 261–68.

[14] F. H. Lahee, *Trans. Amer. Inst. Min. Met. Eng. Petrol. Div.* (1932), pp. 279–94.

[15] R. T. Hill, "The Geology of the Black and Grand Prairies of Texas," *U. S. Geol. Survey 21st Ann. Rept.*, Pt. 7 (1900), pp. 302–28.

[16] Gayle Scott, "Études stratigraphiques et paléontologiques sur les terrains crétacés du Texas," *Doctorate* (Grenoble, France, 1926).

[17] *Idem*, "The Woodbine Sand of Texas Interpreted as a Regressive Phenomenon," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 6 (June, 1926), pp. 613–24.

[18] Gayle Scott, F. B. Plummer, *et al.*, "A Discussion of the Producing Sands of East Texas," *Dallas Petrol. Geol.* (1931). (Mimeographed.)

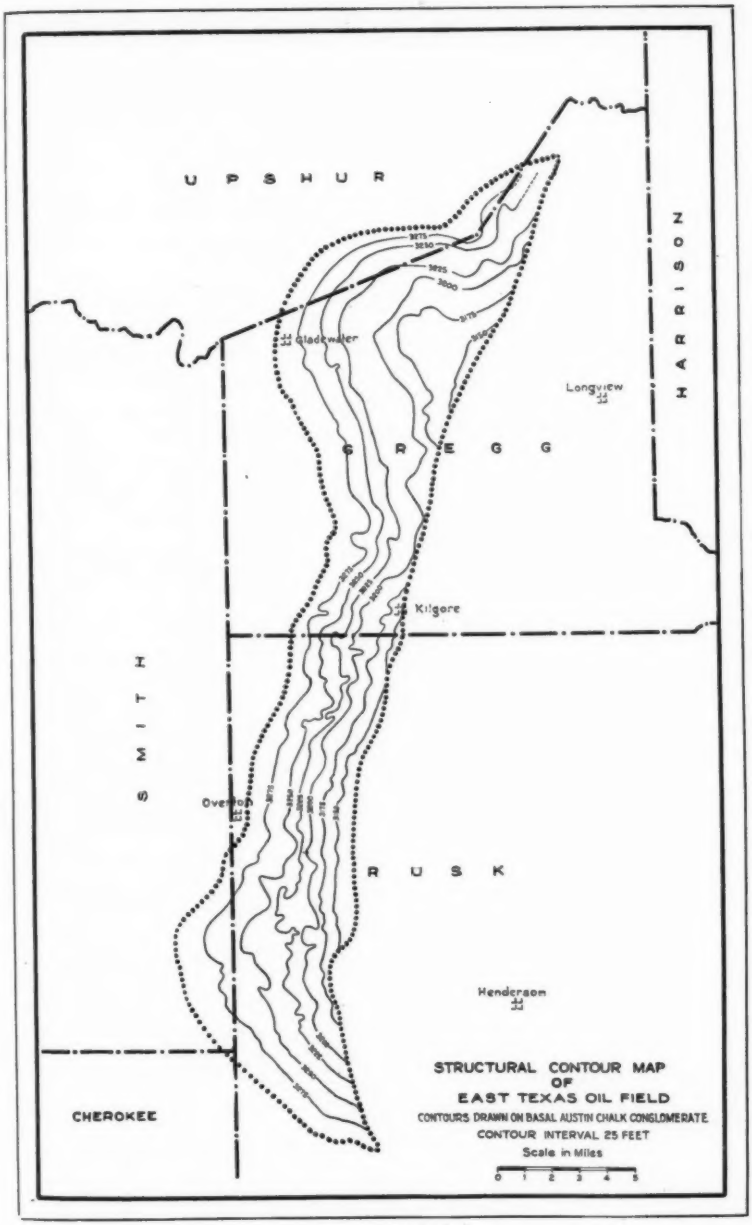
UPSHUR
HARRISON
GREGG
SMITH
RUSK
CHEROKEE
Gladewater
Longview
Kilgore
Overton
Henderson
STRUCTURAL CONTOUR MAP
OF
EAST TEXAS OIL FIELD
CONTOURS DRAWN ON BASAL AUSTIN CHALK CONGLOMERATE
CONTOUR INTERVAL 25 FEET
Scale in Miles
0 1 2 3 4 5

FIG. 6

at a geological symposium held at Dallas, Texas, March 7, 1931. From information at hand the Woodbine-Eagle Ford group can be divided into four zones: (1) a basal clay zone; (2) a lower ash-free zone, predominantly of sand; (3) an upper sand and shale zone which contains ash and other detrital volcanic material as well as brackish-water fossils; and (4) at the top the typical fissile bituminous Eagle Ford shales of the western portion of the basin. Several individuals have field work in progress which will probably go far in clarifying information concerning the vertical and horizontal sequence and variation in these beds.

Within the East Texas field the clay zone at the base of the sand section contains Lower Cretaceous fossils. That this clay zone is the correlative of the clay zone discussed by Hill, Scott, and Plummer may be disputed.

Sands are found within the field which appear to be ash-free and probably belong to the Dexter sand member.

Many of the sands and clays of the field contain detrital volcanic material and are considered to be the equivalent of the Lewisville beds of Hill. Some of these cores contain brackish-water fossils.

It is very questionable whether any of the beds of the Eagle Ford-Woodbine group of the East Texas field proper are as high in the columnar section as the typical Eagle Ford shale of the west side of the basin.

An unconformity has been postulated at the base of the clay section below the main sand zone and above the Washita limestone section. Sufficient evidence is not at hand to determine positively that no such unconformity exists, but the presence of Lower Cretaceous fossils suggests that it is not present. It is believed that no prominent unconformity, if any, exists between this clay zone and the sands deposited immediately above, suggesting that Scott's contention of a regressive period of deposition is correct for the sands of the lower part of the Eagle Ford-Woodbine group of beds.

Due to change in character of sands and overlapping of facies, there appears to be an unconformity within the sand group in the East Texas field. The upper beds, or those containing volcanic material, have a wider areal extent and apparently overlap the sand beds below. In the northern and northeastern part of the field, apparently only the upper sands are present. Farther south, both appear to be present. However, an insufficient number of cores throughout the field has been examined to justify the use of this break for contouring purposes. The unconformity at the base of the Austin chalk is the more important of the two major unconformities as far as the East Texas

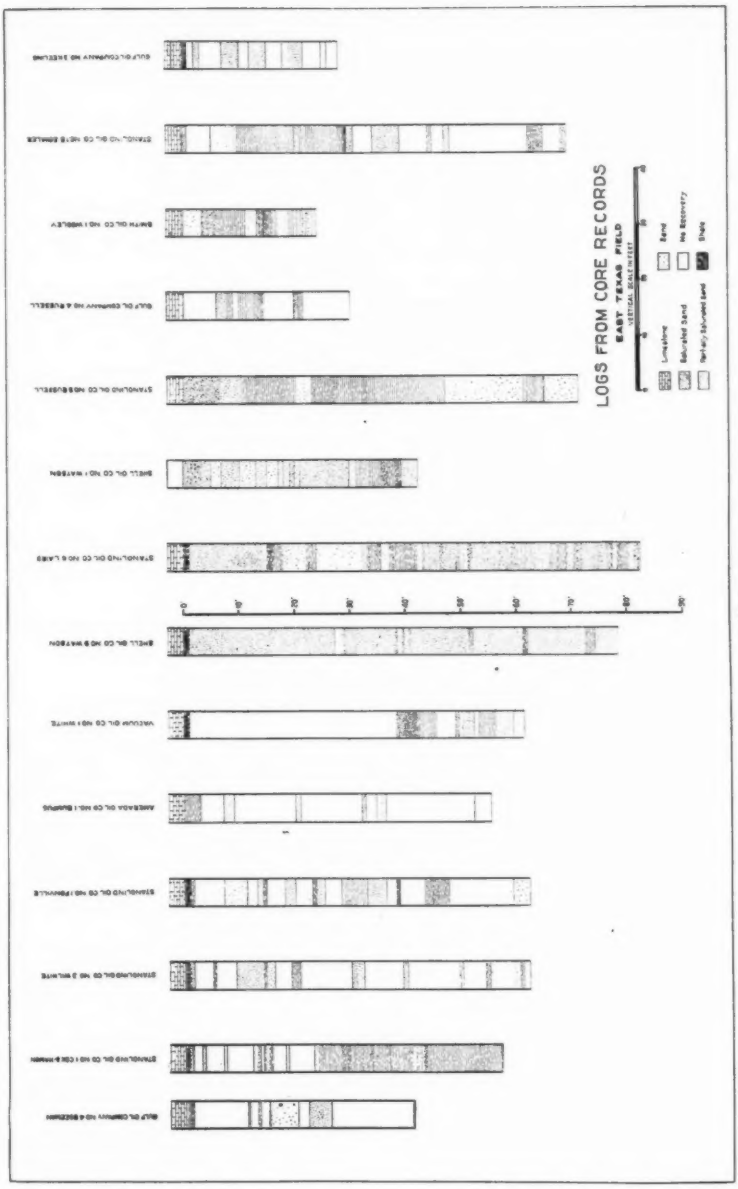
LOGS FROM CORE RECORDS
EAST TEXAS FIELD
VERTICAL SCALE IN FEET
Limestone
Sand
Saturated Sand
No Recovery
Partially Saturated Sand
Shale

FIG. 7

field is concerned since it overlaps both the upper and lower zones and causes the closing of the reservoir on the east.

Prior to the deposition of the Austin chalk, there was intermittent or continuous differential movement, which resulted in the tilting of the pre-Austin chalk beds to the west along the western flank of the Sabine uplift. Associated with these movements were periods of erosion which truncated the inclined pre-Austin chalk beds. At the end of these periods of movement, erosion and deposition, a veneer of conglomerate was left on the eroded surface. This conglomerate is of Austin chalk age, as is indicated by the coarse material imbedded in the base of the Austin chalk. The tilting of the pre-Austin chalk beds, combined with the intermittent erosion and deposition, and followed by the Austin chalk deposition, formed the eastern closure of the field.

The map (Fig. 6) showing the subsurface structure of the field is contoured on the basal Austin chalk conglomerate. The contours more nearly represent an erosional surface than the surface of a single horizon within the producing zone; yet the structural closure is evident. If it were possible to contour a single member within the producing zone, undoubtedly the structure of the field would be more pronounced, for in contouring on the base of the conglomerate, the contours are continued over successively higher beds.

Periodic movement of the Sabine uplift continued into the Tertiary. However, the closing of the East Texas field structure on the north and south was completed early in the Upper Cretaceous. Late Cretaceous and Tertiary movements as well as deposition and erosion increased the magnitude of the Sabine uplift, but only obscured and buried the East Texas field. In consequence, the surface does not reflect the position of the field, but rather the irregularities resulting from late Cretaceous and Tertiary differential movements in the general uplift.

Sand Conditions

To date, the average thickness of the producing sand has not been determined with any degree of accuracy, and it will probably continue to be a debatable question for some time. The lack of better knowledge in regard to sand thickness has been largely due to the orderly manner in which this field has been developed. Under prorated production, each well is restricted to such a small part of its potential flow that a complete change in drilling practice has been brought about; that is, in former years the common practice was to complete wells at their maximum flow, whereas in this field it is the desire of the operator to finish his well in a manner that will insure the allow-

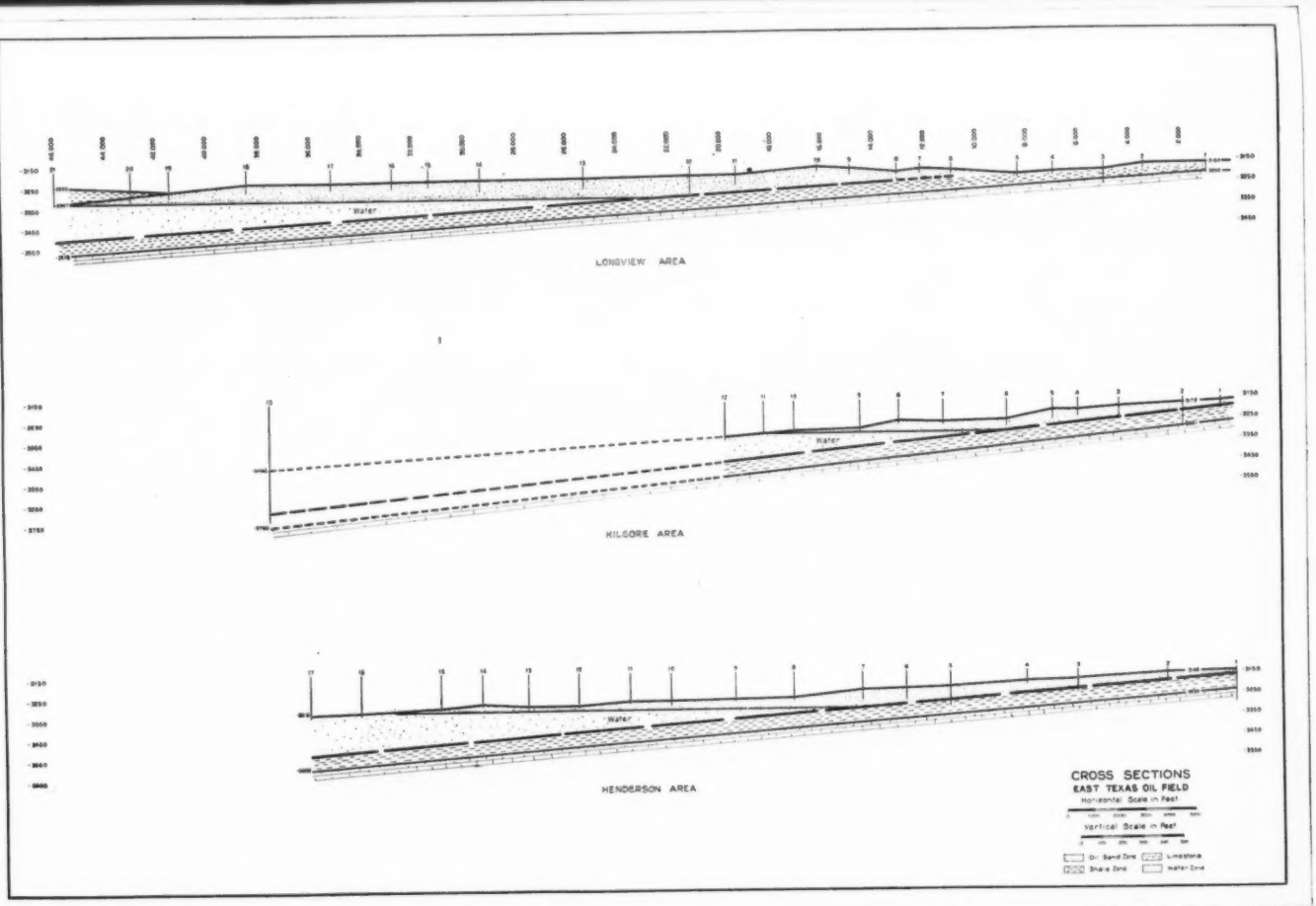
Water
LONGVIEW AREA
Water
KILGORE AREA
Water
HENDERSON AREA
CROSS SECTIONS
EAST TEXAS OIL FIELD
Horizontal Scale in Feet
Vertical Scale in Feet
Oil Sand Zone
Limestone
Shale Zone
Water Zone

FIG. 8

able production, and one which will produce pipe-line oil during the greatest length of time. Due to this change, the majority of the wells have been carried only a few feet into the sand. The ease and certainty with which wells may be completed has made the extensive use of the core barrel unnecessary. The average depth drilled below the top of the sand in 2,500 wells is only 20 feet; therefore it is obvious

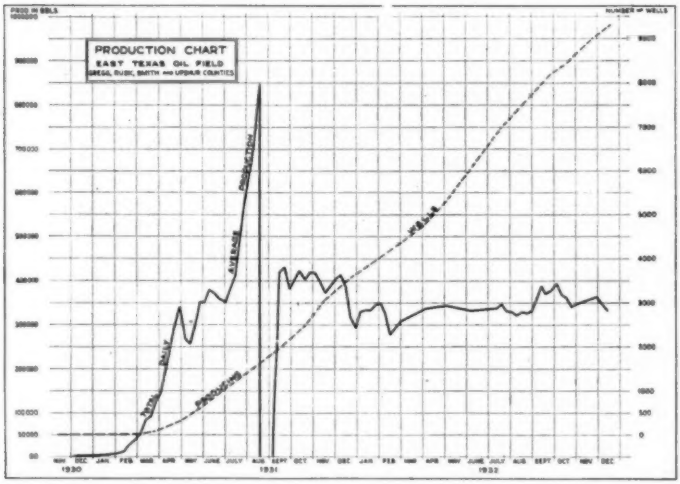

FIG. 9

that with so little penetration in 26 per cent of the wells drilled, only a very meager conception can be had of the actual average thickness of the producing sand.

Cores from approximately 50 wells distributed throughout the field have been examined. The most complete cores observed were from wells of the Stanolind Oil and Gas Company and the Shell Petroleum Corporation, from many of which 60–80 per cent recovery was made. The examination of these cores indicates very definitely that the pay zone of the field is not a single sand, but a series of rather thinly interstratified sands, shales, and ashes, which are in all probability lenticular in nature. However, the readjustment of pressure which took place in wells after the enactment of proration indicates that interconnection of sands has not been destroyed by lensing, or else intercommunication of sands has been established by wells.

The maximum amount of saturated sand seen in any of the cores

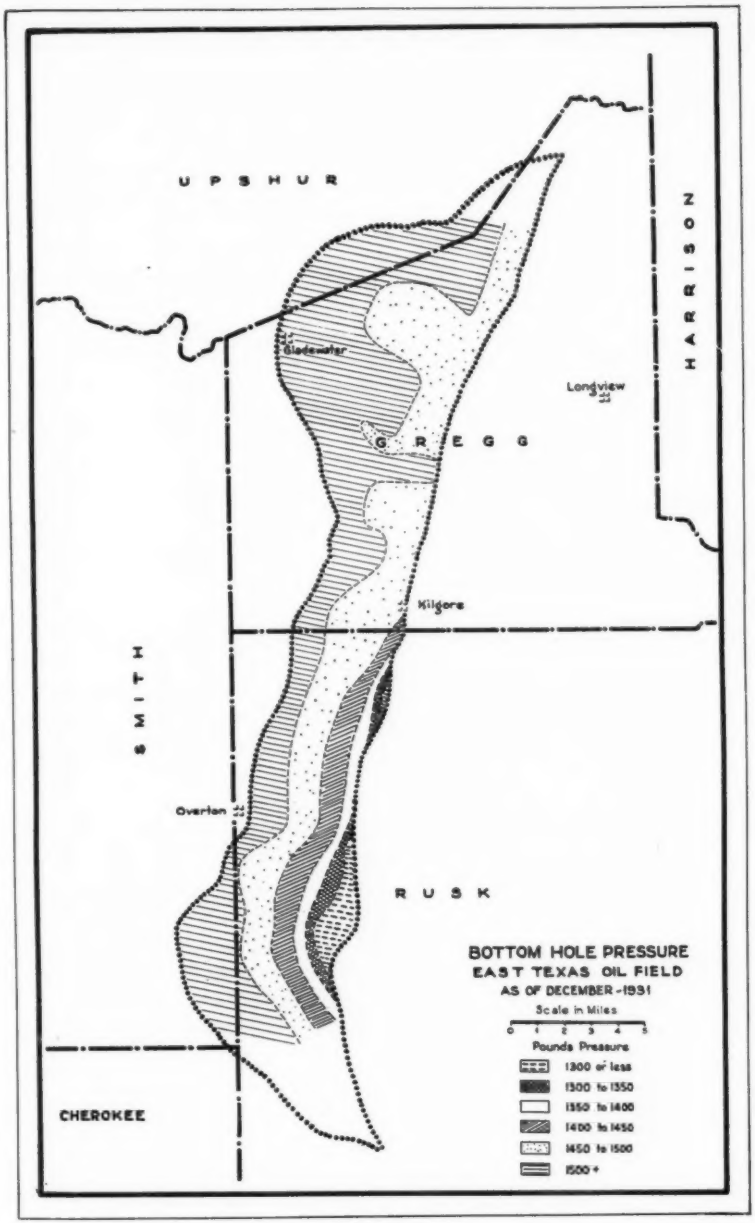
UPSHUR
HARRISON
Gladewater
Longview
GREGG
Kilgore
SMITH
Overton
RUSK
CHEROKEE
BOTTOM HOLE PRESSURE
EAST TEXAS OIL FIELD
AS OF DECEMBER-1931
Scale in Miles
0 1 2 3 4 5
Pounds Pressure
1300 or less
1300 to 1350
1350 to 1400
1400 to 1450
1450 to 1500
1500+

FIG. 10

examined was 40 feet in the Shell Petroleum Corporation's Watson No. 9. The average thickness of all sand logged in cores observed was 22.5 feet, the total amount of sands ranging from 4 feet to 40 feet. One core of excellent recovery showed five separate sands which varied in thickness from 6 inches to 10 feet, all of which were separated by impervious shale and ash beds.

Figure 7 illustrates the character and thickness of beds drilled below the casing seat, or what may be considered the pay zone. Numerous logs could be presented, but the ones taken represent average wells in the various districts.

It is noticeable that the pay zone predominates in sands, sandy shales and ashy material. The natural assumption would be that these beds were all oil-bearing and they no doubt would still be considered as such were it not for the more recent coring of wells. Many sandy shales and ashy sands have been examined from the pay zone which have porosities as high as 18 per cent, yet they show no oil saturation whatever. In the early development, estimates of sand thickness ran as high as 100 feet of saturated oil sand. No doubt these estimates were made in all sincerity, as in many wells 100 feet or more of sandy material had been drilled. It was not until this section had been carefully cored and recovered in numerous wells that the original estimates were proved erroneous.

Cross sections through the Longview, Kilgore, and Henderson areas taken from well records are shown in Figure 8. In the construction of these sections, the top of the sand is shown as recorded in the logs of the wells. It is assumed that the base of the producing sands in the most easterly wells will approximately parallel and conform to the underlying Washita limestone. In support of this assumption it was found that in practically all wells which were drilled deep enough into the section, 75–90 feet of practically barren shales and sandy shales overlie the Washita limestone (Fig. 8). The following wells were used in establishing the Washita control points on the west: the Burnham *et al.* Beck No. 1, west of the Longview area; the Meeker *et al.* Bacon No. 1, west of Kilgore; and an interpolation between the Meeker Bacon No. 1 and the Humphreys Stafford No. 1, southwest of the Henderson district.

By the use of these sections a fair estimate may be made of the average thickness of the producing zone in various parts of the field.

It will be noted that along the western edge of the field, due to the low rate of dip of the sand, the water table creates a wedge very similar to the one caused by the erosion of the sand along the eastern limits of the field. Thus, the bevelling of the sand on the east and the

water-created wedge on the west leave only a narrow strip of the field where the maximum amount of sand is available to the drill. This strip conforms approximately to the −3,220-foot contour.

The examination of cores from approximately 50 wells indicates that the average thickness of saturated oil sand is only 35 per cent of the total section drilled. Therefore, applying this figure to the average thickness of the producing zone in the cross sections, we would have an average thickness of oil sand in the Longview area of 24 feet; in the Kilgore area, 15.4 feet; and in the Henderson area, 16.4 feet; or an average for the entire field of 18.5 feet.

Porosity and Permeability

Tests made on 25 cores taken from 10 representative wells gave an average porosity of 19 per cent. These porosities are not exceptional and fall within the average range of many other fields. The permeabilities of the sands tested are high, giving an average permeability of 1.0 for distilled water (cc./sec./cm.^{2}/atmos./cm.).

Unfortunately, we do not have sufficient permeability data on sands of other fields to make comparisons. However, sands from very good producing fields have permeabilities of .01 or less, which would suggest exceptionally high permeabilities for sands of this field if this comparison were made. The very high initial production of wells finished only a few feet in the sand, and the rapid readjustment of pressures which has taken place, can be attributed largely to the high permeability of the sands of this field.

These very permeable sands have demonstrated the ease and rapidity with which the flow of liquids and pressure adjustments may be made through them. With this in mind, it will not be surprising to see a very rapid encroachment of water as the pressure within the field falls below the effective hydrostatic head, unless a restricted flow is maintained throughout the field, thus maintaining an even advance and rise of the water table. Particularly is it true of this field on account of the flat dipping sands where an average of 16,000 feet of the western side of the field was initially underlain by bottom water. Excessive flow of wells in any of this territory would immediately start water coning and consequent trapping of oil by the water.

Production

Nine months after the completion of the discovery well, the production of this field had reached a total of approximately 900,000 barrels per day. The pressure was declining in many parts of the field and many wells in the most favorable parts of the field ceased to flow.

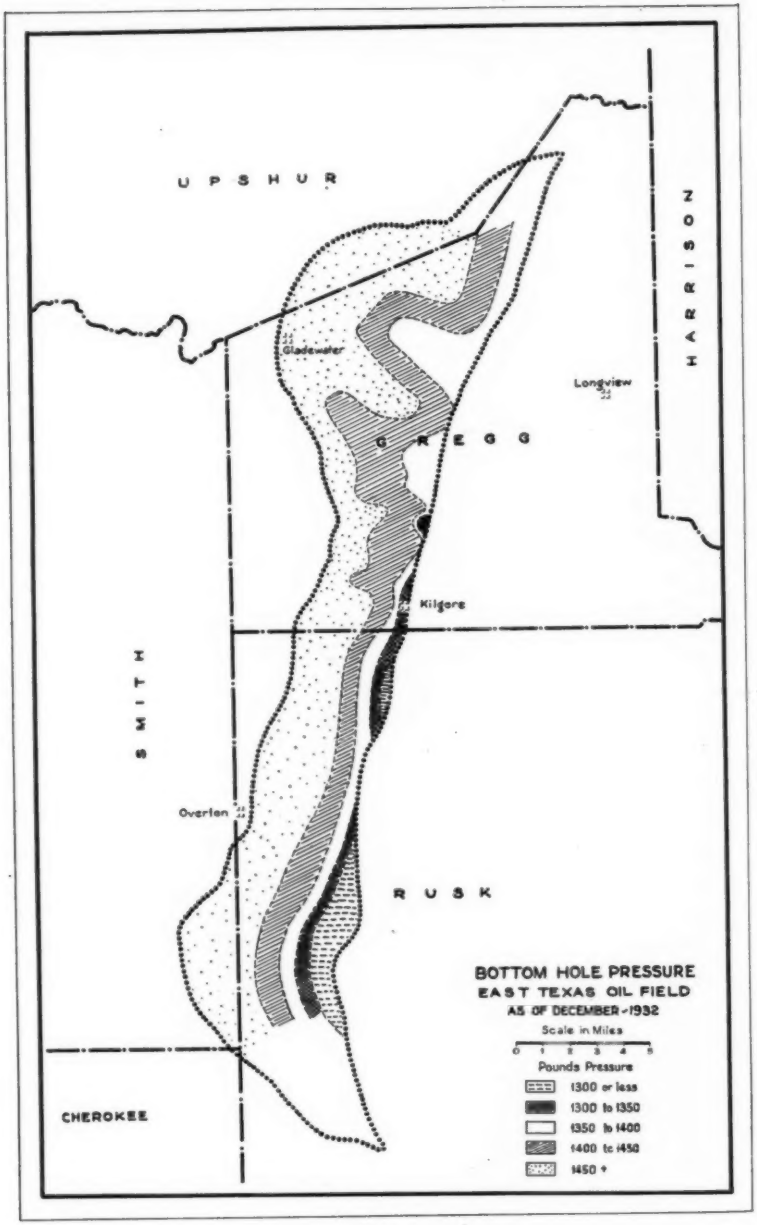
UPSHUR
HARRISON
Gladewater
Longview
GREGG
Kilgore
SMITH
Overton
RUSK
CHEROKEE
BOTTOM HOLE PRESSURE
EAST TEXAS OIL FIELD
AS OF DECEMBER-1932
Scale in Miles
0 1 2 3 4 5
Pounds Pressure
1300 or less
1300 to 1350
1350 to 1400
1400 to 1450
1450 +

FIG. 11

Water was rapidly making inroads into the field. Steps were taken to restrict the enormous flow of oil but before this could be accomplished, the market was becoming demoralized. On August 17, 1931, the entire field was closed down for a period of 19 days under military order and on September 5, 1931, it was reopened under prorated flow which is being maintained. After the first shut-down in August, 1931, a complete readjustment of pressure occurred and many dead wells resumed their flow under normal pressures.

In Figure 9 are shown progress curves of field production and well completions. It will be noted that completions have been made at an average rate of 87.6 wells per week. The increased rate in completions has necessitated a progressive reduction in the allowable production per well.

All of the drilling in the East Texas field is by the rotary method. Depths to the producing sand range from 3,540 to 3,850 feet, depending on the location in the field and the elevation of the well. Wells are drilled at an average cost ranging from $20,000 to $25,000. The majority of wells are equipped with tubing on completion for the purpose of conserving the gas energy by reducing the gas-oil ratio of the flow. Wells are drilled and completed in the average time of 18 days. The estimated average production of initial wells varied from 10,000 to 15,000 barrels.

Pressure

The maximum bottom-hole pressure originally recorded in the field was slightly more than 1,600 pounds per square inch. In Figures 10 and 11, graphic maps are shown indicating the general pressure distribution throughout the field. The progressive pressure change is seen by comparison of Figure 10, showing pressures as of December, 1931, with Figure 11, constructed from pressures existing in December, 1932. As indicated on the maps, the pressure decreases toward the east, with the lowest pressures, of 900–1,100 pounds, occurring in the vicinity of the Joiner discovery area. The gradation of pressures from west to east would normally be attributed to the direct influence of the water drive from the west.

Water

The eastward projection of the present water level (Fig. 8) indicates that 20,000 feet of the Longview area, 10,000 feet of the Kilgore area, and 19,000 feet of the Henderson area are underlain with bottom water. The wells used in establishing these levels are The Texas Company's Waddell No. 1 at −3,300 feet in the Longview

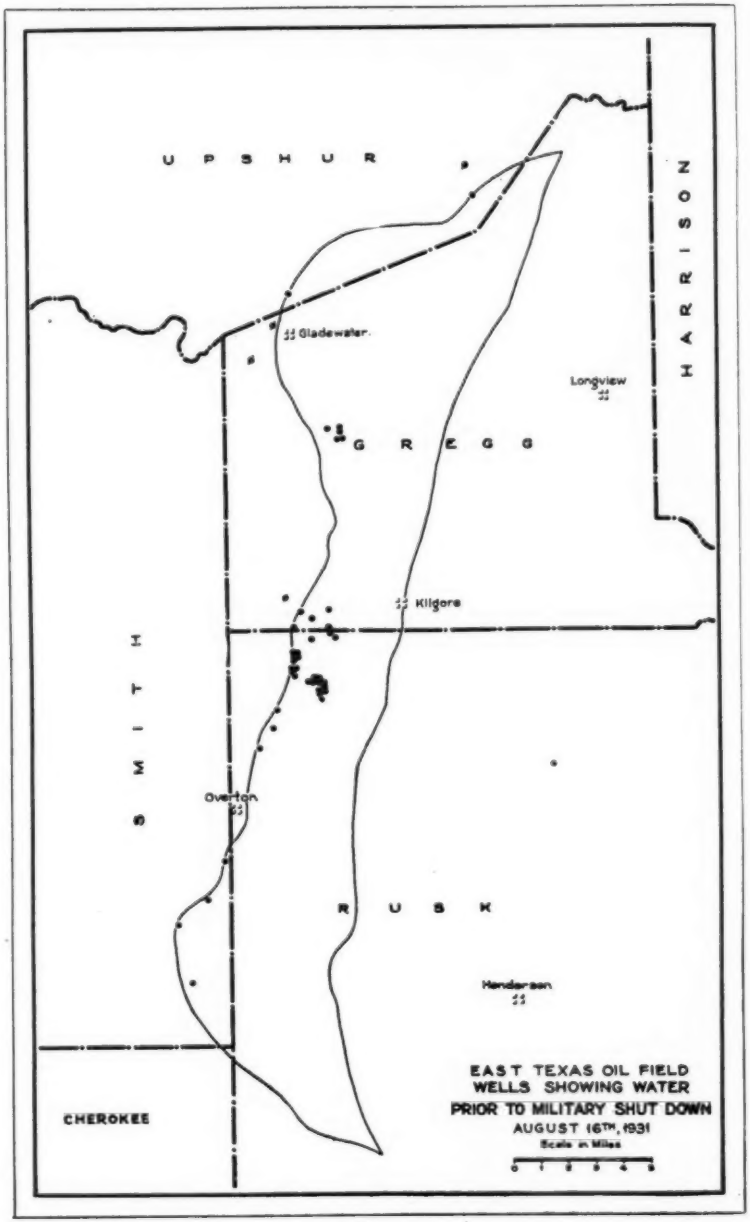
U P S H U R
H A R R I S O N
Gladewater
Longview
G R E G G
Kilgore
S M I T H
Overton
R U S K
Henderson
CHEROKEE
EAST TEXAS OIL FIELD
WELLS SHOWING WATER
PRIOR TO MILITARY SHUT DOWN
AUGUST 16TH, 1931
Scale in Miles
0 1 2 3 4 5

FIG. 12

area, the Sun Oil Company's Barker No. 1 at −3,309 feet in the Kilgore area, and Deering and Sons' Goforth No. 1 at −3,304 feet in the Henderson area.

These encroachment distances, applied to the entire field, show 58,000 acres, or more than 50 per cent of the field, to be underlain with bottom water at the present time (January, 1933).

The lack of immediate and pronounced water encroachment has caused some doubt as to the effectiveness of the water drive. The withdrawal of 234 million barrels of oil, which would void 150,678 acre feet of sand of 20 per cent porosity, has had apparently little effect on the movement of the edge water. This is not surprising when it is considered that 58,000 acres of the field are already underlain with water and such a withdrawal would account for a vertical rise of only 3.9 feet in this area.

The ability of salt water to maintain field pressures has been entirely lacking in sand fields of which the writers have any knowledge.

The quantity of flow of water into a field is dependent on the differential pressure between the effective hydrostatic head and the bottom-hole pressure within the field. As long as field pressures are sufficiently high to flow the oil, the differential pressure will necessarily be low. Consequently, the maximum amount of water ingress will take place after the field has lost its flowing pressure and wells are being pumped from near bottom.

The Powell field, occupying a similar position with reference to the East Texas synclinal basin, being subjected to the same general hydrostatic head, and deriving its oil from the same Woodbine sand members, should be comparable, relatively, to the East Texas field. As an illustration, the Powell field, of 2,800 acres, produced 214,000 barrels of fluid per day, 112,000 barrels of which was water, from 700 pumping wells, 6 months after the peak of production was reached. The present daily withdrawal of fluid is 68,000 barrels, 2,800 of which is oil, from 165 wells.

Approximately 75 per cent of the wells in the Powell field are pumping with tubing submerged from 100 to 200 feet. The fluid stands in these wells from 100 to 1,200 feet from the bottom. The fluid level has remained practically stationary throughout a considerable period of time. Wells closed down for 3–6 months have shown no appreciable rise in fluid level when pumping was resumed.

The fluid level remaining practically constant indicates that the influx of water at its present differential pressure, which is much lower than the original field pressure, is not in excess of 68,000 barrels per day. If the present fluid level were allowed to rise to flowing height

(though it is doubtful if original pressures would ever be re-established, as shown by the inability of the fluid to rise in wells closed in for long periods of time), the present inflow of 68,000 barrels would be greatly reduced. With such a reduction in flow, the impracticability of flowing a field by hydrostatic energy alone is obvious. It is therefore evident that the flowing life of fields of this type depends principally upon its gas energy. However, restricted flow will undoubtedly play a very important part in the control of fluid levels and prevent the development of local low-pressure areas due to excessive flow which were rapidly making their appearance during the open-flow period of the East Texas field. So long as restricted flow and uniform pressure sufficiently high to flow the wells exist within the field, comparatively little salt water ingress can take place.

However, at a time when the pressure shall have declined to a point where pumping will have to be resorted to, with a consequent drop in fluid level, an increasing differential pressure between the hydrostatic head and bottom-hole pressure will be created.

If it is possible to make a comparison of the future water conditions which will exist in the East Texas field with the existing water conditions of the Powell field, we find that Powell, with its 2,800 acres of producing area and its 9 miles of frontal sand exposure, has reached a stage where fluid levels remain constant under a 68,000 barrel fluid withdrawal. If this analogy is applied to East Texas, then when equilibrium between fluid levels and withdrawals has been established, an influx of approximately 408,000 barrels of water can be expected through the 50 miles of frontal sand along the basinward limits of the field. However, as in the case of Powell, when near-bottom pumping occurs in the majority of wells, the differential pressure will be so increased that the East Texas field will be capable of producing possibly 700,000 barrels of water daily.

The result of continuous pumping of 10,000 wells is obvious, provided the maximum ingress of water into the field at the minimum bottom-hole pressure is not more than 700,000 barrels.

Rapid water advancement will, therefore, be held in check until the field pressures adjacent to the water fall below the effective hydrostatic head.

A great many of the west side wells in the East Texas field are completed only 2–6 feet in the sand, and it is not unlikely that the uniform field pressures being maintained by restricted flow will cause such wells to pass from pipe-line oil wells to water wells in a very short interval of time, thus avoiding the cost of producing large quantities of water in order to drain the sand of its oil.

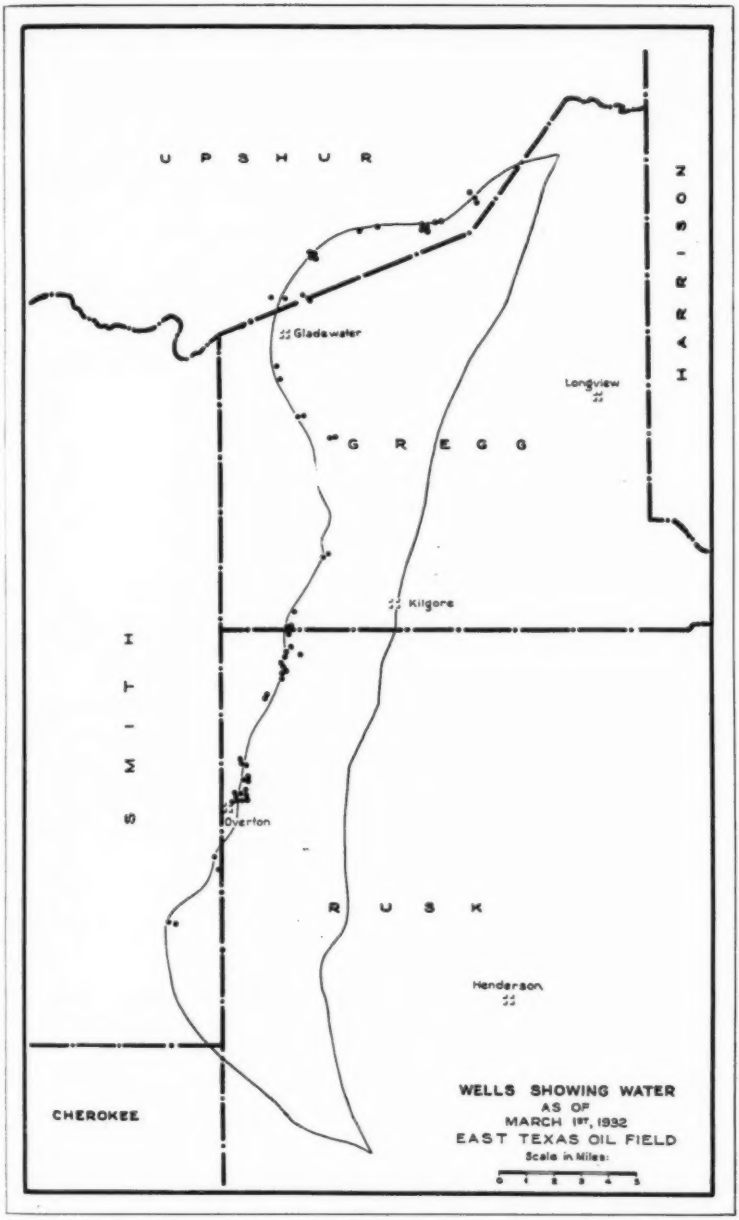
UPSHUR
HARRISON
Gladewater
Longview
GREGG
Kilgore
SMITH
Overton
RUSK
Henderson
CHEROKEE
WELLS SHOWING WATER
AS OF
MARCH 1ST, 1932
EAST TEXAS OIL FIELD
Scale in Miles:
0 1 2 3 4 5

FIG. 13

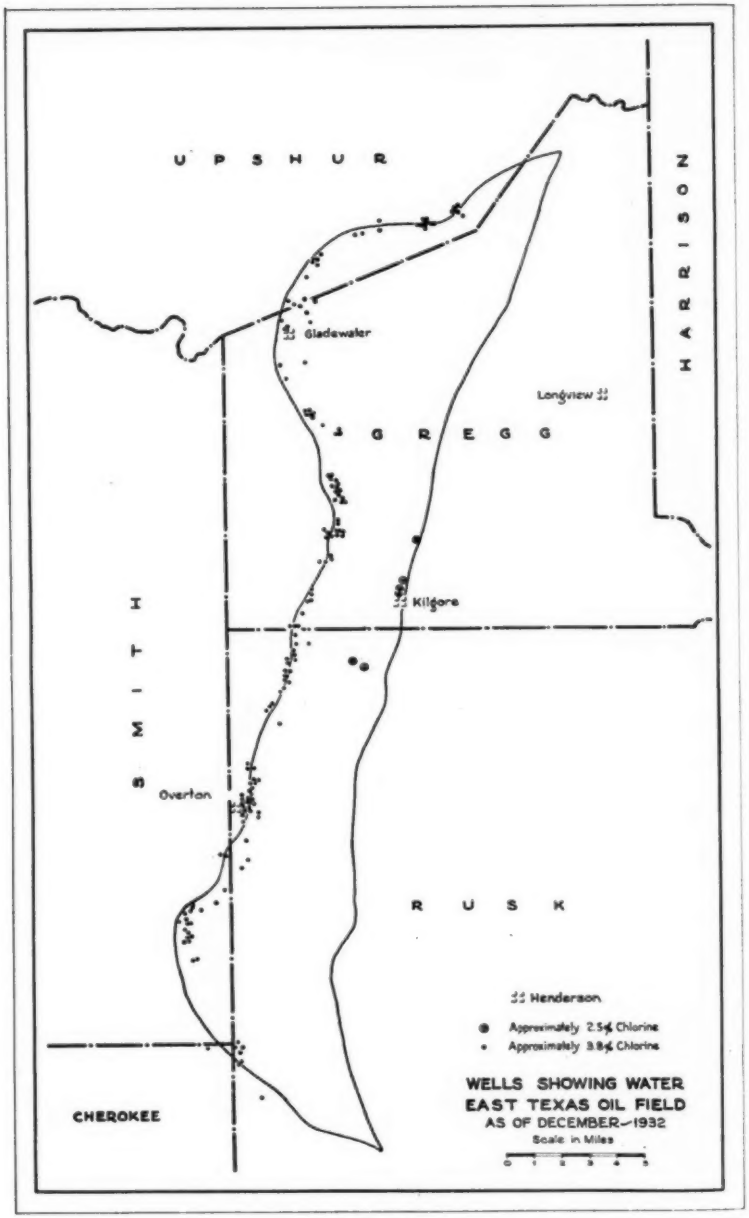
U P S H U R
H A R R I S O N
Gladewater
Longview
G R E G G
Kilgore
S M I T H
Overton
R U S K
CHEROKEE
Henderson
Approximately 2.5% Chlorine
Approximately 3.8% Chlorine
WELLS SHOWING WATER
EAST TEXAS OIL FIELD
AS OF DECEMBER—1932
Scale in Miles
0 1 2 3 4 5

FIG. 14

In Figures 11, 12, and 13 are shown sketch maps of the field. One indicates the location of wells which were making water on August 16, 1931, or during the unrestricted flow of the field. The second sketch represents wells making water as of March 1, 1932, and the third, wells making water as of January 1, 1933.

Many of the interior wells have been plugged back since the shutdown of the field. However, it is interesting to note that not a single well is reported to be making water in the interior of the field at this time, demonstrating the beneficial effects of restricted flow on the control of water coning.

Water analyses have been made of a sufficient number of wells throughout the field to show that the water is practically identical in wells several miles apart. The Woodbine water of the East Texas field is of the secondary saline type, having approximately twice as much concentration of dissolved salts as ordinary sea water. An average analysis will show approximately 67,000 parts per million; the average chlorine content being approximately 40,000 parts per million, or 4 per cent. In recent months a few wells along the eastern side of the field have shown some water, but analyses of the water showed 2.5 per cent or less of chlorine, indicating that the source of this east-side water is not the same as the western flank water developed by wells which encountered the pay at too great a depth or were drilled too deep into the section.

The bevelling of the main producing sands on the east has left only the thin basal portion of the main producing sand along the eastern side of the field. Consequently, wells drilled along this eastern margin of the field are compelled to drill much deeper into the section than wells located in the center of the field in order to find sufficient sand to make commercial wells. Many of these wells are carried to the Washita limestone and include in their settings all sands and sandy shales lying between the base of the Austin chalk and the Washita limestone.

It is very probable that these deeper sands and sandy shale members, though thin and lenticular, contain oil held in place by water. Due to the thinness and lenticularity of these members, the oil content is not large and already sufficient oil has been withdrawn from them to allow the edge water of these pay sands to make its appearance. There is a possibility, if this proves to be the case, of this edge water becoming a top-water menace to adjacent down-dip wells. Wells of this class making 2.5 per cent chlorine water are indicated in Figure 14.

The placing of the East Texas producing horizon into its correct

position in the Eagle Ford-Woodbine group on the west is difficult on account of lack of paleontological information. Although the continuity of the East Texas sand is somewhat in doubt, the water analyses in Table I are presented to show the marked similarity of the waters of the Van field, Van Zandt County, the Amerada Petroleum Corporation's Wade No. 1, Upshur County, and the field waters of East Texas.

TABLE I
WATER ANALYSES

	East Texas Field		*Upshur County*	*Van Field*
	Kilgore	*Longview*		
	Nat. Securities Vernon No. 1	*Stanolind Everetts No. 1*	*Amerada Wade No. 1*	*Humble Blake No. 2*
Sodium and potassium	24,540	24,653	25,185	24,325
Calcium	1,388	1,432	1,452	1,417
Magnesium	282	335	350	401
Sulphate	278	259	110	42
Chlorine	40,598	40,598	42,245	41,000
Bicarbonate	569	387	250	256
Total	67,649	68,964	69,592	67,441
Secondary alkalinity	0.8	1.8	0.2	0.36
Primary salinity	92.0	91.5	91.6	91.08
Secondary salinity	7.1	6.6	8.2	8.56

These waters are practically identical and support the contention that the producing sands of the field are correlative with the Woodbine sands on the west, though subsequent geological nomenclature may alter their relative position in the geological section.

SUMMARY

As previously stated, the average thickness of saturated sand in all cores observed was 22.5 feet. The average thickness of sand as indicated by the cross sections, which are broader in scope, was 18.6 feet. Therefore, by allowing an average thickness of 20.5 feet of sand of 20 per cent porosity and 45 per cent recovery, a total ultimate production of approximately 1,600 million barrels would result, or an average yield of approximately 14,000 barrels per acre.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 7 (JULY, 1933), PP. 793-815, 2 FIGS.

DISTRIBUTION OF OIL POOLS IN KANSAS IN RELATION TO PRE-MISSISSIPPIAN STRUCTURE AND AREAL GEOLOGY[1]

JOHN L. RICH[2]
Cincinnati, Ohio

ABSTRACT

A map of the pre-Mississippian areal geology of Kansas reveals a broad regional uplift, here called the Central Kansas arch, extending west-northwestward across the state. North of the arch is the North Kansas basin, and south of it the Dodge City basin, which is the north limb of a greater geosynclinal trough in central Oklahoma. A map of the oil pools of the state superimposed on that of the pre-Mississippian areal geology shows clearly that the pools tend to lie along the broad geanticlinal crest of the Central Kansas arch and seems to show, though less distinctly, a relation to the pre-Chattanooga "outcrop" of the Simpson formation.

The distribution of oil pools to be expected under the hypothesis that the oil of Kansas was generated, during the Appalachian revolution, in the deep geosynclinal basins of southern Oklahoma and has migrated northward through certain porous carrier beds and accumulated under the control of the structural and geological conditions existing at that time—before the more recent westward tilting of the region—seems to agree fairly closely with the actual distribution as now known. Whether this agreement indicates the correctness of the hypothesis or is due merely to coincidence remains an open question to be decided by future developments.

INTRODUCTION

In two preceding papers[3] it was suggested that much of the oil of Kansas may have been generated on the borders of the high carbon-ratio areas and in the deep Pennsylvanian geosynclinal basins in southern Oklahoma and have migrated northward out of the basins through certain porous carrier beds, the most important of which are thought to have been the sands of the Simpson formation and the weathered upper portion of the Arbuckle limestone. If such was the origin of the Kansas oil, and if the general structure and the distribution of the carrier beds in relation to the structure had been known, it should have been possible to predict the general location of the oil accumulations.

As a result of drilling, the broader features of the structure and the

[1] Manuscript received, May 16, 1932.

[2] University of Cincinnati.

[3] John L. Rich, "Function of Carrier Beds in Long-Distance Migration of Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (August, 1931), pp. 911–24; "Source and Date of Accumulation of Oil in Granite Ridge Pools of Kansas and Oklahoma," *Bull. Amer. Assoc Petrol. Geol.*, Vol. 15 (December, 1931), pp. 1431–52.

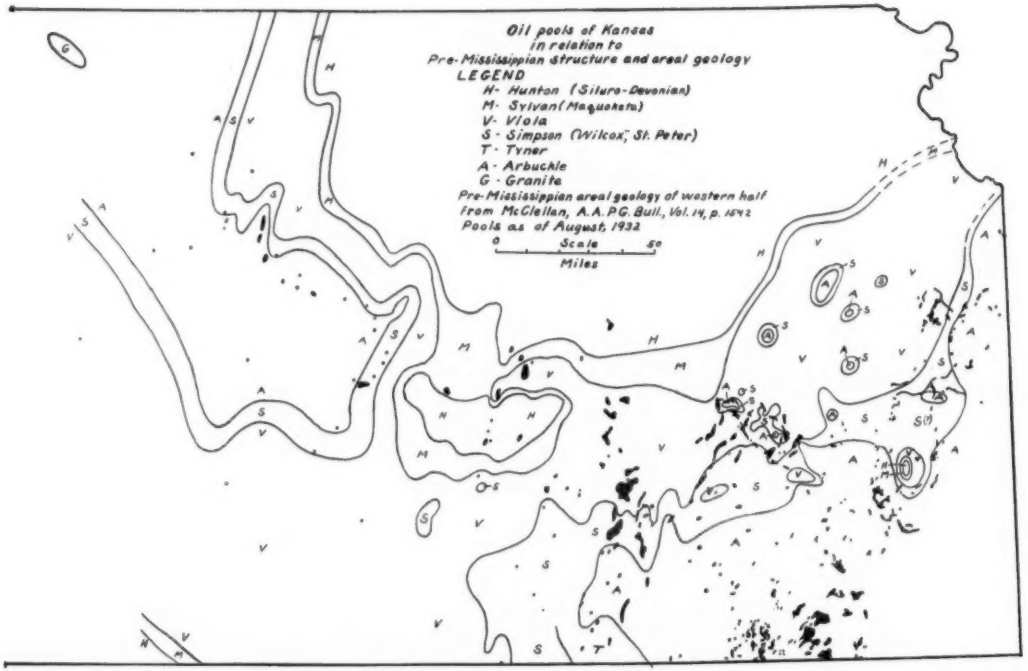

FIG. 1.—Distribution of oil pools in Kansas in relation to pre-Mississippian structure and areal geology.

geological relations of the carrier beds to that structure at the time when the oil migration and accumulation are believed to have occurred can be reconstructed. The purpose of the writer is to make that reconstruction and to compare the actual distribution of the oil as known to date with what should have been expected.

PRE-MISSISSIPPIAN AREAL GEOLOGY

Figure 1 is an areal geological map of Kansas as it was at the close of the period of erosion immediately preceding the deposition of the Chattanooga shale (early Mississippian). The west half of this map, from the site of the Granite ridge westward, is taken with practically no modification from a map by McClellan.[4] The part east of the Granite ridge has been compiled by the writer. This portion of the map must be considered as a progress map which will necessarily be changed in details as more information becomes available. In compiling the map it was necessary to rely mainly on drillers' logs because samples were available from only a minority of the wells, especially in the eastern part of the area. Each log was interpreted[5] and its location and a symbol for the pre-Chattanooga formation encountered was entered on the map. Boundary lines were then drawn, so far as possible without prejudice as to assumed structural trends, so as to enclose areas having like symbols. Because of scarcity of samples in the eastern part of the area, considerable changes may be necessary there when and if more definite information becomes available.

Figure 1 differs from the map published by McClellan in that, on account of more detailed information having become available, greater complexity is shown on the eastern half of the map, and also in that the Granite ridge uplift, which did not occur until after Chattanooga time, does not appear. For the western part of the area, northwest of central Barton and Russell counties, Figure 1 is inconsistent in that it shows the areal geology of the pre-Mississippian formations beneath the Pennsylvanian cover instead of beneath the Chattanooga because the Mississippian rocks (Chattanooga shale and "Mississippi lime") are not present there.

Pre-Mississippian structure is inferred from pre-Mississippian

[4] Hugh W. McClellan, "Subsurface Distribution of Pre-Mississippian Rocks of Kansas and Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 12 (December, 1930), pp. 1535–56.

[5] Grateful acknowledgment is made to J. V. Howell, Anthony Folger, and Mrs. Fanny C. Edson for assistance in checking the interpretation of many of the logs, but they can not be held accountable for any errors in the map because in some instances, where sample information was not available, the writer's interpretation rather than theirs was used in the compilation.

areal geology on the assumption that the Chattanooga shale was laid down on an almost perfectly level surface and that, therefore, the "outcrop" of one of the older of the pre-Chattanooga formations beneath the Chattanooga indicates a bevelled uplift and the "outcrop" of one of the younger formations indicates a basin.

As may be seen from Figure 2, the principal structural features revealed by the pre-Mississippian areal geology are: (1) the Central Kansas arch,[6] extending as a broad, compound geanticlinal uplift in the form of an open arc convex toward the south from near the southeastern corner of the state westward and northwestward to the north line of the state in Norton and Decatur counties; (2) the North Kansas basin, including what was later separated by the uplift of the Granite ridge (Nemaha Mountains) into the Salina basin on the west and the Forest City basin on the east; (3) the Dodge City basin, occupying the part of southwestern and western Kansas south and southwest of the Central Kansas arch; (4) the Ozark monocline, comprising the eastern part of the state where the pre-Chattanooga dip was primarily west-northwestward into the North Kansas basin. The Ozark monocline had a very gentle westward inclination and was broken by a number of low domes whose extent and trend can not yet be determined definitely on account of insufficient information. The most prominent of these interruptions to the general monoclinal dip into the North Kansas basin are found in central Osage and northern Lyon counties where the Arbuckle limestone underlies the Chattanooga; in southwestern Lyon County where the Arbuckle appears; and in northeastern Greenwood County where the Simpson and Arbuckle formations underlie the Chattanooga. A possible basin has been indicated in central Allen County, but knowledge of it is based on only three logs whose accuracy is open to question. It is shown on the map merely to indicate the possible presence of a basin there and to direct attention to that area if more information becomes available.

Attention is again drawn to the major Central Kansas arch, and to an east-west structural basin situated mainly in northern Harvey and Reno counties, which divides the lower saddle-like portion of the arch into two low and somewhat irregular subsidiary arches.

[6] As here used, the term "Central Kansas arch" is made to include the whole of the uplifted arc here described. Its eastern end has been called the Chautauqua arch by Barwick (John S. Barwick, "The Salina Basin of North Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12 No. 2 (February, 1928), pp. 177–89) and its dome-like up-bulge in Barton, Rush, Ellis, and the adjoining counties has been called the Barton arch by Barwick and the Central Kansas uplift by Morgan (L. C. Morgan, "Central Kansas Uplift," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16 No. 5 (May, 1932), pp. 483–84). The lower, compound saddle along the arch between these features has, so far as known to the writer, remained unnamed.

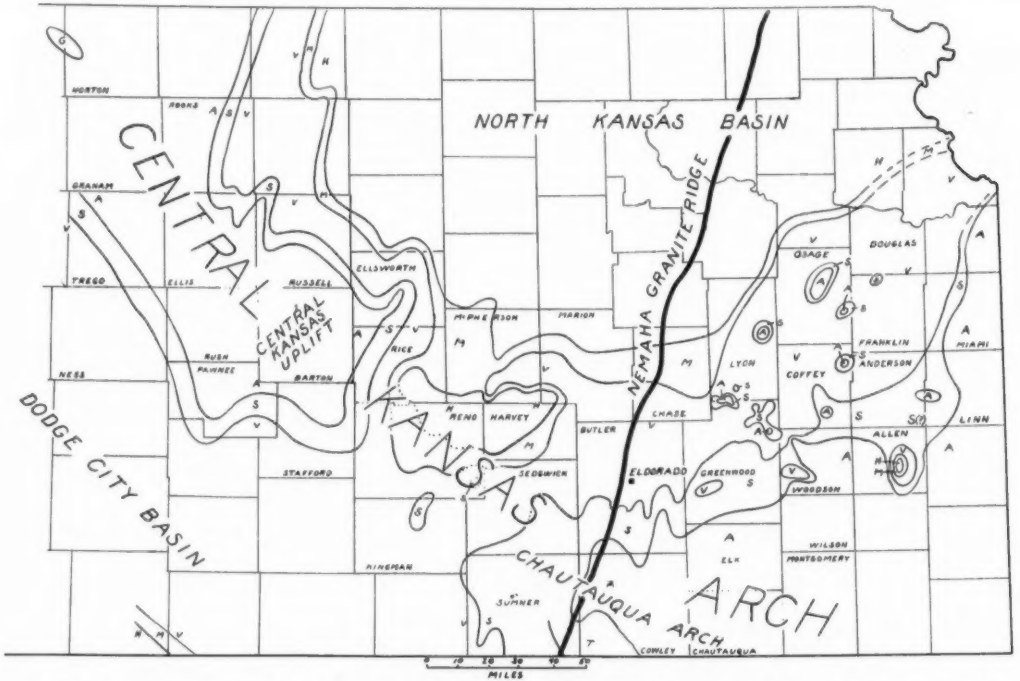

FIG. 2.—Key map showing location of various features described in text superposed on a county map for ready reference. Hunton basin, shown in Allen County, is based on doubtful logs and its existence is therefore open to question pending further drilling.

POST-MISSISSIPPIAN CRUSTAL MOVEMENTS

After the Mississippian Chattanooga shale and "Mississippi lime" had been laid down unconformably over the pre-Mississippian areal geology shown on Figure 1, the structure as there shown was disturbed by three major events, all probably nearly contemporaneous: (1) uplift, westward tilting, and partial erosion of a great monoclinal block, the Nemaha Granite ridge, along the line indicated in Figure 2; (2) subsidence of that portion of Kansas east of the Granite ridge and the deposition of Cherokee (Pennsylvanian) sediments in the basin thus formed; (3) renewed uplift and erosion of Morgan's Central Kansas uplift in Barton, Russell, Rush, and adjoining counties, with probable contemporaneous sinking of the Dodge City and Salina basins and deposition of Cherokee sediments in them. These events were followed by general subsidence of the entire region and the deposition of a thick body of Pennsylvanian rocks over the entire state.

The deposition of the Pennsylvanian rocks was accompanied by a southward tilting of at least the southern part of the state as is shown by the southward thickening of the Pennsylvanian sediments. As a result, the southward dip of the pre-Mississippian formations on the south side of the Central Kansas arch was increased and the effective crest of the arch was shifted somewhat northward from its original position, as shown in Figure 1, to the northern of the subsidiary arches of which the Central Kansas arch is here made up. Such a change is indicated by the greater depth to the pre-Mississippian rocks on the subsidiary arch south of the Harvey-Reno County basin than on the one north of it.

The distribution and structure of the pre-Mississippian formations of Kansas during the late Pennsylvanian and Permian periods, when, according to the hypotheses under discussion, the principal migration of oil is supposed to have taken place, may therefore be reconstructed as being much the same as shown in Figure 1 except for the following features: (1) the southward dips from the Central Kansas arch were greater; (2) the effective crest of the arch was farther north than before; and (3) the Granite ridge uplift had produced a sharp southward-plunging up-fold of the pre-Mississippian formations. On this up-fold as far north as Eldorado the pre-Mississippian rocks were present beneath the Pennsylvanian, but north of that point the upper part of the pre-Mississippian formations, which are here looked upon as possible carrier beds for the oil, had been eroded from the crest,[7]

[7] Still farther north all of the pre-Mississippian rocks were stripped off and the Pennsylvanian rocks rest directly on the pre-Cambrian along the crest of the ridge.

so that their "outcrops" beneath the Pennsylvanian cover must have extended northward along the gently dipping west flank of the Granite ridge, and may have extended northward in a narrow belt of steeply upturned rocks along the eastern flank, provided the eastern flank is not faulted. If, as seems likely, the pre-Pennsylvanian formations along the east side of the Granite ridge are in fault contact with it, no such sub-Pennsylvanian outcrop would have occurred.

WORKING HYPOTHESIS RESPECTING OIL MIGRATION

If oil was generated in the deep geosynclinal basins of southern and southeastern Oklahoma either before or during the period of Appalachian mountain building, and migrated northward out of the basin mainly through the porous Simpson and Arbuckle carrier beds, working its way up out of them at every opportunity and accumulating in higher beds or migrating farther in the higher beds as conditions might permit, where would the oil have accumulated?

It seems clear that the Central Kansas arch would have been the dominant structural feature governing oil accumulation in Kansas. Oil would have worked northward toward the crest of the arch, but, in the absence of a strong northward artesian circulation, it could not have descended far into the North Kansas basin on either the west or the east side of the Granite ridge.

The Granite ridge uplift, which at that time was a strong up-fold crossing the Central Kansas arch, would have been an especially favorable place for oil accumulation as far north as Eldorado,—where the carrier beds were involved in the folding—and for a part of the distance north-northwest of Eldorado,—as far as the carrier beds on the west flank of the Granite ridge lay on the broad crest of the Central Kansas arch. North of Eldorado the carrier beds had previously been removed by erosion from the crest of the Granite ridge, so that the crest of that ridge should have been unfavorable from Eldorado north. On the east flank of the Granite ridge north of Eldorado the carrier beds are either faulted down against the granite or are upturned steeply on the east side of the uplift. If down-faulted, conditions were unfavorable for oil accumulation; and if steeply upturned, any accumulations which may be present may easily have remained undiscovered because of the narrowness of the belt which they must occupy.

On the Central Kansas arch the oil accumulations should, in general, be expected to be most numerous in areas where the Arbuckle or the Simpson carrier beds, or both, "outcrop" beneath the Chattanooga or Pennsylvanian shale cover, or where they are not sepa-

rated from the Chattanooga by any considerable thickness of post-Simpson rocks (the presence of which would imply a basin which would have been avoided by migrating oil). In the general areas outlined above, favorable local structures affecting the carrier beds should have caused accumulation, and fissuring on local structures and general upward leakage should have produced accumulations in reservoir beds above the carriers. Considerable secondary migration in these upper beds would probably have occurred and might have extended for considerable distances beyond the limits of the carrier beds through which the oil originally traveled.

Local structures anywhere in the Dodge City basin should have interrupted some of the migrating oil and caused accumulation, but unless such structures were numerous, the greater part of the oil migrating across the area would, presumably, have continued northward toward the crest of the Central Kansas arch.

That portion of the arch in southeastern Kansas (the Chautauqua arch) should have been structurally favorable for oil accumulation, but not so favorably situated with respect to carrier beds as the crest of the arch farther west. To the extent that the Arbuckle limestone may have served as a carrier bed, the Chautauqua arch would have been favorably situated, but oil traveling through the Simpson formation could have reached the crest of the arch only by secondary migration in higher beds.

Inasmuch as the area of pre-Chattanooga outcrop of the Arbuckle limestone extends westward across the axis of the Granite ridge uplift on the crest of the Chautauqua arch, the pre-Chattanooga outcrop of the Simpson formation bordering it is so disposed that oil migrating northward through the Simpson sands could not have followed them northeastward into that part of the state north of the crest of the Central Kansas arch without making at least one crossing of the Granite ridge uplift, which, it seems, would have trapped most, if not all, of the oil. For this reason, little oil should be expected to have reached that portion of Kansas east of the Granite ridge and north of the Chautauqua arch through Simpson carrier beds, unless belts of Simpson rocks, which were not revealed by the information available for the preparation of Figure 1, cross the Chautauqua arch east of the Granite ridge. If the oil in eastern Kansas came from the south, it seems, therefore, that it must have migrated mainly through the Arbuckle limestone or through higher beds and should be expected to show no distinct relation to the pre-Chattanooga outcrop of the Simpson sands in that locality.

SECONDARY POST-MIGRATION REARRANGEMENTS

Because the porous Ordovician carrier beds (sheet sands and limestones) of eastern Kansas, and also some of the Pennsylvanian sands in the eastern part of the area, seem to have been flushed by water taken in at their outcrop on the west flank of the Ozark dome, considerable secondary westward migration of oil has probably occurred in the eastern part of the state. Its effect would have been to form a belt of secondary concentration of oil parallel to the strike of the Ozark monocline. The water from the outcrop seems to have oxidized and rendered heavy the oil in the lower Cherokee sands in the eastern part of the oil belt of eastern Kansas and also the small amounts of oil which have been found in the deeper, more continuously porous Arbuckle and Simpson beds of that region.

It is also possible that in the more porous beds secondary up-dip (eastward) migration may have occurred following the post-Pennsylvanian westward tilting of the region. Such migration should have occurred soon after the tilting and should have preceded the westward concentration by circulating water described above.

The low saline content of the waters of the Ordovician rocks of northern Kansas, as revealed by Dott and Ginter,[8] may indicate a southward water movement from the outcrop in Minnesota. If this occurred in post-Pennsylvanian time it may have combined with the influence of the Central Kansas arch to prevent migration of oil into the basins of northern Kansas.

DISTRIBUTION OF OIL POOLS IN KANSAS AS KNOWN TO DATE

The actual distribution of oil in Kansas as of August, 1932, is shown in Figure 1. Attention is specifically called to the fact that the oil pools there shown occur in beds at many different horizons, from the Arbuckle and Simpson formations at the base, upward to sands high in the Pennsylvanian.

The broad facts of distribution shown on the map may be summarized and briefly explained as follows.

1. No oil pools appear in the southeastern corner of the state. In that area the Pennsylvanian sands which contain oil farther west have either been removed by erosion, occur in outcrop, or lie at shallow depths and locally contain very heavy, tar-like oil. The deeper beds carry fresh or nearly fresh artesian water and, presumably, have been flushed of any oil they may formerly have contained.

[8] Robert H. Dott and Roy L. Ginter, "Iso-Con Map for Ordovician Waters," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 9 (September, 1930), pp. 1215–18.

2. A belt of numerous pools and "shoestrings" extends northeastward from the south line of the state in Chautauqua and Montgomery counties through Allen, Anderson, and Linn, to Franklin and Miami counties. Almost all of these pools occur in Pennsylvanian sands. To some extent the belt seems to be determined by the distribution of sand bodies suitable for reservoirs. It may also be, in part, a belt of secondary concentration as explained in a preceding paragraph.

3. A group of pools in which the oil occurs mainly in the top of the "Mississippi lime" is found in eastern Greenwood, western Woodson, and southwestern Coffey counties.

4. A belt of "shoestring" pools extends southwestward across the state from northern Greenwood County. These pools produce from the Bartlesville sand of the Cherokee formation (Pennsylvanian). They mark a shore line or a succession of shore lines on the west side of the East Kansas Cherokee basin and appear to correspond with a similar belt of "shoestring" sands, containing mostly gas, lying on the east side of the basin in the belt of pools described in paragraph 2. The general lack of pools between these two belts (except the pools in the "Mississippi lime" described in paragraph 3) seems to be due mainly to a lack of reservoir sands in the Pennsylvanian, especially of those in the Bartlesville zone.

5. A conspicuous group of large pools follows the crest of the Granite ridge uplift as far north as Eldorado, and the west flank of that uplift for a considerable distance farther north. These pools produce mainly from the Arbuckle, Simpson, and immediately overlying formations, though Lost Springs, at the extreme north end, produces from the top of the "Mississippi lime."

6. A belt of scattered pools extends west-northwestward through central Kansas, following in general the broad top of the Central Kansas arch, but showing a tendency toward concentration on the northern of the subsidiary axes composing that arch. Concentrations of pools in this belt are localized by the north-northeastward trending Fairport anticline in Russell and Ellis counties and the Abilene arch in McPherson County, both superposed upon the older Central Kansas arch. The oil from these pools comes mostly from the Arbuckle, Simpson, and Viola[9] formations and the top of the "Mississippi lime," but some of the pools at the extreme northwestern end produce from the lower part of the Pennsylvanian system where it lies unconformably over the Arbuckle limestone or the pre-Cambrian.

[9] The Oklahoma names are used in this paper, but it is recognized that the formations probably are not exact equivalents of those in Oklahoma.

Several pools have recently been discovered in the area of Simpson "outcrop" along the eastern margin of the pre-Mississippian Arbuckle area on the Central Kansas uplift in Ellsworth, Rice, Stafford, and adjoining counties.

Oil development in that part of the state has been in progress for only a few years and is still active. Several of the oil pools, represented in Figure 1 by dots, are in the discovery-well stage. Undoubtedly the present pools will be extended and others discovered.

7. A conspicuous lack of pools is to be noted in the North Kansas basin, except within a very few miles of its southern edge. No commercial oil pools have been found in that region despite the fact that considerable drilling has been done and that much of it was guided by geological advice based on the structure of the surface rocks which are well exposed in that part of the state.

8. A scarcity of oil pools is noticeable along the south side of the Central Kansas arch west of the Granite ridge and in the Dodge City basin. This condition does not necessarily mean that oil is not present, for the region is still inadequately tested because (a) attention has only recently been directed to it; (b) on account of lack of key beds in the surface rocks, the geological structure can be worked only by means of the core drill and geophysical instruments; the basin is very deep and costly wells are required to reach the Arbuckle and Simpson formations.

COMPARISON BETWEEN EXPECTED AND ACTUAL LOCATION OF OIL POOLS

Comparison of the actual location of the Kansas oil accumulations as now known with the locations which should be expected under the hypotheses outlined above reveals many points of agreement, some of seeming disagreement, and others whose significance can be determined only after further developments.

Among the points of agreement, attention is called to the following.

1. A distinct grouping of pools along the Central Kansas arch.

2. A conspicuous concentration of major pools along that portion of the Granite ridge uplift which lies on the crest of the Central Kansas arch, and an absence of known accumulations farther north along the Granite ridge, where the carrier beds have been stripped from the top of the ridge.

3. A grouping of pools (most of them still in the very early stages of development) along the Simpson "outcrop" where it crosses the crest of the Central Kansas arch in Ellsworth, Rice, and Stafford counties.

4. Absence, so far as known to date, of commercial oil pools in the North Kansas basin. The pool farthest north on the rim of that basin, the Lost Springs pool of Marion County, lies about 9 miles north of the pre-Mississippian "outcrop" of the Siluro-Devonian rocks (Hunton of Figure 1). This pool is producing from the top of the "Mississippi lime" and may well be a product of secondary migration in that formation. In that event, no downward migration into the North Kansas basin would be required, for that basin is pre-Mississippian and affects the "Mississippi lime" little if at all. It is, of course, possible that important pools in the North Kansas basin remain to be discovered but the negative results of considerable drilling make their presence seem doubtful. So far as is known to the writer, the geological section in that basin is as favorable with respect to possible source material for oil and certainly as favorable with respect to reservoir beds as in any other part of the state. The presence of many oil pools on the Central Kansas arch and their seeming absence in the North Kansas basin at least suggests strongly that oil migration from the south has been stopped by that arch.

5. Seeming absence of important oil pools in the northern third of extreme eastern Kansas. So far as known, reservoir conditions and possible source rocks are as favorable there as elsewhere.

6. Seeming barrenness of the Bartlesville "shoestring" sands north of the pre-Mississippian high areas in southern Lyon and northeastern Greenwood counties. The Bartlesville shoestring pools of Butler and Greenwood counties are mostly in or close to the areas of pre-Chattanooga "outcrop" of the Simpson formation and they are all on or south of the pre-Mississippian high just mentioned. The shoestring sands continue northward from the producing area into Lyon County, but have there been found to carry water in all tests to date, in spite of the fact that they are not now lower with respect to sea-level than they are in the producing areas farther south. Farther northeast in Franklin, Douglas, and eastern Osage counties several bodies of Bartlesville "shoestring" sand have been found to contain only water and some gas.

7. Distribution of oil in the "Mississippi lime" east of the Granite ridge. In that area, oil pools and oil showings in the upper part of the "Mississippi lime" are found mainly in the areas of pre-Chattanooga Simpson outcrop. The "Mississippi lime" pools extend eastward from near Eureka, Greenwood County, through the Virgil, Gridley, and Neosho Falls districts to Blue Mound in southern Linn County (noncommercial at present in the latter district because the oil is heavy).

Whether this relation to the Simpson is significant or accidental remains to be determined.

Among the points of possible disagreement the following may be mentioned.

1. The belt of numerous oil pools and "shoestrings" trending northeastward in eastern Kansas (not including the pools of Greenwood, western Woodson, and Butler counties already discussed) is not confined to the Chautauqua arch and shows no very definite relation to the pre-Chattanooga Simpson "outcrop," though the northern part of the belt lies mainly in or near the area of that "outcrop." As was pointed out in a preceding paragraph, close relation to the Simpson "outcrop" is not to be expected in this region unless an undiscovered belt of Simpson sands crosses the Chautauqua arch east of the Granite ridge. The East Kansas belt of pools may be due in part to secondary concentration caused by water descending the Ozark dome, from the flanks of which the Pennsylvanian formations bearing the oil sands have been stripped, so that any oil once present in them was probably carried westward by water circulation. It is possible, also, that the belt of pools may be due in part to oil floating at the top of the water table in certain of the higher Pennsylvanian sands. This is suggested by the fact that the sand bodies containing some of the east-west "shoestring" pools can be traced down dip (westward) into water, but do not seem to contain any water at their eastern ends, where they have an appearance, in many places, of having been drained of their oil, for the more porous beds are oil-stained but not oil-saturated and only the finer beds and cross-bedded strata retain "live" oil, seemingly because in those beds it was trapped and could not drain out westward as the water table dropped.

2. The fact that west of the Granite ridge a considerable number of the pools discovered to date are along the northern of the subsidiary axes of the Central Kansas arch and even on local structures in the Harvey-Reno County pre-Mississippian basin might be taken as evidence that the oil did not come from the south. In explanation of the observed condition it may be pointed out, however, that the post-Chattanooga southward tilting of the region shifted the crest of the arch northward, as already explained, so that the northern axis would have become the final trap for northward migrating oil, and also that, on account of that tilting and the resulting notable southward thickening of the Mississippian and Pennsylvanian sections south of the arch, the pay sands there lie deeper and have been less thoroughly tested. The greater number of pools on the northern subsidiary axes may, therefore, not be out of harmony with the theory

here proposed and they may, in part, represent merely the results of more thorough testing.

3. Few pools have been found in the Dodge City basin. As already explained, this condition may be due to inadequate testing.

4. The comparatively small number of oil pools on the southern subsidiary axes of the Central Kansas arch south of the Harvey-Reno County basin does not accord with expectations. Inadequate testing on account of relatively great depth and difficulty in determining subsurface structure may explain this condition. The results of further drilling in that area will be especially significant in connection with the problem under discussion.

If further drilling reveals important pools in the North Kansas basin and in extreme northeastern Kansas, their discovery will constitute strong evidence against the hypothesis here outlined. On the other hand, failure of future drilling to reveal important pools along the southern subsidiary axes of the Central Kansas arch, in the Dodge City basin, and especially in the vicinity of the Simpson and the top of the Arbuckle "outcrops" around the south side of Morgan's Central Kansas uplift, will be evidence against the hypothesis, though less conclusive.

CHATTANOOGA SHALE POSSIBLY POOR SEAL FOR OIL ACCUMULATIONS

If the Chattanooga shale were an effective impervious bed it should be expected to have caused large accumulations of oil at many places where the Simpson sands are bevelled and covered by it. The actual distribution of the pools, however, does not seem to bear out this expectation. Such correspondence as may exist in eastern Kansas between the location of the pools and the pre-Chattanooga outcrop of the Simpson sands seems to be shown mainly by oil pools in higher beds. If there is any causal connection between pre-Chattanooga Simpson outcrop and the location of the pools, it must, therefore, depend on the upward escape of oil from the Simpson and its trapping in higher sands.

Consideration of the physical nature of the Chattanooga shale makes it seem possible that it is entirely ineffective as a seal on account of excessive jointing. Oil shales such as make up much or all of the Chattanooga are characteristically brittle and highly jointed. Both the Chattanooga shale and the overlying "Mississippi lime," which also is brittle, may therefore have constituted ineffective seals for oil migrating in beds below and have permitted ready upward escape of oil, especially on folds or along belts of shattering.

CONCLUSION

The purpose of the writer has been to point out the geological and structural features of Kansas as they existed at the time when, according to the hypothesis previously outlined, oil generated in southern Oklahoma may have migrated northward into the state; to deduce the general location of oil accumulations which should have been expected under that hypothesis and in view of the then existing geological and structural conditions; and to compare the results of these deductions with the actual distribution of oil accumulations as known to date.

The actual distribution of oil seems to agree rather closely with what should have been expected. Whether that result indicates the correctness of the hypotheses from which the deductions were made, or is due to mere coincidence, or to other causes which have not been discovered, may well be left for further investigation.

DISCUSSION

FANNY C. EDSON, Tulsa, Oklahoma (written discussion received, April 7, 1933): When a geologist undertakes to make "an areal geological map of Kansas as it was at the close of the period of erosion immediately preceding the deposition of the Chattanooga shale," his only source of information is the records of wells which have been drilled in the area he wishes to map. Even if the well records be perfect, the map constructed from them does not show the areal distribution of the formations as they existed at the beginning of Mississippian time, but shows the present areal distribution of the pre-Chattanooga formations; the present distribution of those formations differs from the pre-Chattanooga distribution by the amount, character, and direction of the accumulated orogenic movements from Chattanooga to present time.

Well records, unfortunately, are far from perfect, and in the part of Kansas east of the "Granite ridge" they are particularly poor. Samples are available from only a very small proportion of the wells drilled; most of the driller's logs are old and very inaccurate. The stratigraphers who have examined all of the available samples in eastern Kansas have independently reached remarkably uniform conclusions regarding the formations penetrated by each well. With such definite information as a background in eastern Kansas, and with other definite information based on samples, as to the stratigraphy and structural trends in the remainder of Kansas, these same stratigraphers have interpreted the drillers' logs of the wells in eastern Kansas where samples are not available. Again independently, they have reached uniform conclusions as to the areal distribution and structural trend of the pre-Mississippian formations in eastern Kansas, conclusions that are diametrically opposed to those set forth by Rich. The opposing conclusions, together with the sample determinations and consequent drillers' log interpretations which induced the conclusions, all were made available to Rich.

Rich states:

> Boundary lines were . . . drawn, so far as possible, without prejudice as to assumed structural trends . . . .

A paragraph or two later he says:

> Pre-Mississippian structure is inferred from pre-Mississippian areal geology on the assumption that the Chattanooga shale was laid down on an almost perfectly level surface and that, therefore, the "outcrop" of one of the older of the pre-Chattanooga formations beneath the Chattanooga indicates a bevelled uplift and the "outcrop" of one of the younger formations indicates a basin.

He then proceeds to list four

> principal structural features revealed by the [his] pre-Mississippian areal geology.

If one is to construct an areal geologic map which can not help but show structural trends, would it not be well during its construction to bear in mind the known major structural trends?

Rich evidently means his term Central Kansas arch to supersede and include Morgan's Central Kansas uplift, yet he speaks of the "Central Kansas uplift in Ellsworth, Rice, Stafford, and adjoining counties," and again of "the Central Kansas arch in Ellsworth, Rice, and Stafford counties." Since the term Central Kansas uplift was introduced by Morgan in 1932 it has been adopted by most stratigraphers working in Kansas and is associated in their minds with a definite structural province. For this reason the writer believes the introduction of the term Central Kansas arch as defined is unwise and its adoption would cause unnecessary confusion.

Exception is taken to this statement:

> These events [pre-Cherokee orogenic movements] were followed by general subsidence of the entire region and the deposition of a thick body of Pennsylvanian rocks over the entire state,

for the reason that the oldest marine Pennsylvanian rocks deposited in Kansas vary markedly in age from place to place, and in some localities are not older than upper Lansing.

It is the opinion of the writer that the premises as to stratigraphy and structure on which Rich has based his hypotheses are unsound, and therefore his deductions are open to serious question.

J. V. Howell, Ponca City, Oklahoma (written discussion received, April 14, 1933): A number of statements in this paper appear open to question, some as to fact, and others as to interpretation. This is particularly true of the map (Fig. 1) showing the areal distribution of the beds beneath the Chattanooga shale, and inasmuch as the author bases much of his argument on the structure indicated on this map, such criticism appears fair.

Few will question the fact that at the close of the Devonian, the Forest City and Salina basins were one, and the term, "North Kansas basin," as used to describe this original feature, is useful. But since the map attempts to set forth the conditions exactly as they existed at the close of the erosion interval preceding Chattanooga time, it seems somewhat out of place to show the Nemaha ridge, which did not exist until much later. As Rich states, the western part of the map is inconsistent in that it shows pre-Pennsylvanian distribution on the Central Kansas uplift (Mississippian beds being absent) and it seems equally inconsistent in treatment of the Nemaha area, where

Mississippian beds also are absent. Therefore a false idea of structure is obtained, since the distribution of beds in the western part of the area may have been chiefly controlled by post-Mississippian, rather than pre-Mississippian erosion. The writer would prefer using the same treatment throughout.

Although little has been published on the subject, all who have recently studied Ozark structure (notably Buehler, McQueen, and Greene) agree that a most prominent feature is the northwest-southeast "grain," and that the Ozark mass consists of a series of strong, elongate, sub-parallel folds, which originated in early Paleozoic (or even pre-Cambrian) time and were periodically active at least as late as the post-Devonian (Caledonian) revolution. Some were rejuvenated also at the close of the Mississippian, and during Lansing (Pennsylvanian) time. Many of these northwestward plunging folds can be traced from the Ozarks into eastern Kansas, and several can be shown to have extended entirely across the present site of the Nemaha ridge. Inasmuch as the Chattanooga was deposited on a surface which bevels these folds, the distribution of the older formations must be controlled by this structure pattern, yet Figure 1 gives no indication of such a condition. Rich states that he has drawn the boundaries "without prejudice as to assumed structural trends," and were the trends really assumed, the writer would agree. But as they admit of proof, the practice appears unjustified. There is a great deal of evidence that the many isolated areas of Simpson and Arbuckle shown in the Forest City basin are located on northwestward trending axes.

If the oil in Kansas has been formed, as suggested by Rich, in the Ouachita geosyncline, and been moved northward some 300 miles to its present resting place, it must be assumed that water also moved similarly, and that the flow was *outward* from the basin, during and following the Appalachian revolution. In explaining accumulation in the Cherokee sands, however, the author assumes that since that time the movement of water was basinward, thus implying a complete reversal of water circulation. This seems questionable.

In explaining the presence of oil in the Pennsylvanian, the author argues that the Chattanooga shale (which he refers to as an oil shale!) and the Mississippian limestones, are sufficiently brittle to permit fracturing and the consequent passage of oil. Such a view seems untenable because of the known lithology of these beds, but even greater doubt is cast on the possibility by reason of the marked difference in character of the waters above and below the Mississippian. Except near the outcrop, the Ordovician waters generally show a high sulphur content, whereas appreciable amounts of sulphur are rare in the Pennsylvanian. It is difficult to see how oil could pass through such fissures without the water accompanying it.

He also ignores the fact that in practically all fields in which the Chattanooga is present over the trap, accumulation occurs in that porous zone which lies immediately beneath the shale. Either the Chattanooga is the source bed or it is a most effective cap rock, or it may be both.

It seems much easier to explain the distribution of the Kansas pools by assuming a near-by source. Every important pre-Mississippian accumulation occurs in traps where the Ordovician (or Devonian) beds are in contact with the Chattanooga, Cherokee, or perhaps Marmaton shales. All of these are highly organic and all are relatively impervious. The Bartlesville sand is a member of the Cherokee, and the other important Pennsylvanian producers,

the eastern Kansas shoestrings, and the Layton-Kansas City sands, are adjacent to Cherokee or Marmaton. Is this only a coincidence?

Rich cites also the barrenness of the Nemaha folds north of Eldorado, and attributes this to absence of carrier beds. Actually, however, Ordovician rocks occur along the ridge for a long distance north of Eldorado. But they are here in contact with Pennsylvanian rocks ranging from about Kansas City on the Burns dome, to Oread at Cottonwood Falls, and even higher beds at the Nebraska line. The Chattanooga is missing throughout this stretch, so that absence of the usual source beds seems quite adequate to explain the scarcity of oil.

It would seem hazardous at present to rule out such large and little known areas as northeastern, north-central, and southwestern Kansas as potential producers. Much remains to be learned about all of these areas, and not many geologists will agree that they have been adequately tested. Many dry holes were drilled along the west flank of the Sabine uplift before the East Texas field was discovered, and Kansas fields are much smaller targets.

ANTHONY FOLGER, Wichita, Kansas (written discussion received, May 16, 1933): The discussions already furnished by Mrs. Edson and J. V. Howell render it difficult to contribute additional remarks relative to this paper. However, in the light of the wide divergence existing between the opinions of most Kansas geologists, and the opinions expressed by Dr. Rich, I wish to re-emphasize a number of points already stressed and make a few additional comments.

Dr. Rich's paper is primarily an attempt to explain the geographic and geologic position of the oil fields in Kansas in accordance with his previously published theory of oil migration. The theory can not be proved definitely by Dr. Rich or wholly disproved by the opponents of his hypothesis. Unfortunately, Dr. Rich does not have the confidential data which are in the files of oil-producing companies. Many of these data contradict his theory.

Mrs. Edson and Mr. Howell have discussed the pre-Mississippian subareal map of Kansas. Several Wichita geologists join me in feeling that Dr. Rich's map is unsatisfactory. Even in local areas of satisfactory subsurface control, all lines of geologic research must be considered and evaluated in the preparation of any subareal map. When such a subareal study is extended to include the area embraced by a state, these same principles become even more obligatory. It is doubtful if Rich has had either the time or the available data to prepare the necessary structural and isopach maps of Kansas prerequisite to such a problem. From such maps logical conclusions may be drawn which guide in the assembly of subareal maps. Various oil companies have slowly built up such maps through years of intensive research, and in general these agree that the dominant trend of the older structural axes in Kansas is northwest-southeast. Available evidence clearly shows that these structural axes were developed prior to the post-Devonian peneplanation. Accordingly all pre-Chattanooga formational boundaries must swing around these pre-Chattanooga axes or high areas. Dr. Rich, admittedly, has disregarded these pre-existing structural features. As a result, his subareal contact lines, east of the Granite ridge, are held to be erroneous. It is most unfortunate that this subareal map, on which Dr. Rich relies so largely in the application of his theory, should have been prepared without guidance from a supplemental set of the maps here described. A subareal map of eastern Kansas has been

published recently by Howell[10] which represents the interpretations of many Kansas geologists.

In some places there is an apparent agreement of present oil development with portions of Dr. Rich's theory. This agreement results from limited control or the entire absence of data. Thus, in the comparison of the North Kansas basin and the so-called Dodge City basin with much of the eastern Kansas area, the conclusions for the western area rest on either one well in a county or very few wells in each county, while in the eastern area there are hundreds of wells in a county. Dr. Rich, properly, calls attention to this situation. But has it been emphasized with sufficient force? In my opinion an insufficient number of tests have been drilled in the North Kansas basin, the so-called Dodge City basin, and several other areas considered by the author, to permit formulation of any hypothesis of oil migration. So few tests have been drilled in these areas, which are vitally important in testing the validity of the theory, that the opponents of the Rich hypothesis could bring forward an entirely different set of arguments, just as incapable of proof, to explain in other ways the present distribution or lack of distribution of oil fields in these vital areas.

Finally, I believe that Dr. Rich has unintentionally omitted at least one very important consideration in explaining the distribution of oil fields. He has discussed in detail the producing areas within the several geographic units outlined. But he has not discussed those localities, equal in structural relief to the producing localities, which have been drilled and found barren of oil. Within the area concluded to be most favorably situated for oil accumulation under the hypothesis presented, there exist a number of domes, over whose crests the Ordovician carrier beds extend. Nevertheless, several tests have shown each dome to be barren. Specifically, in central Ellsworth County and east-central Russell County, there are barren domes of far greater structural relief than any present known producing area within the central Kansas uplift. The Halstead dome in northern Harvey County is another severe disappointment. Similarly, a structure is dry in western Sedgwick County, although it is on the same axis of folding as the Valley Center field and has even greater structural relief than this field. It is sufficient to state that an embarrassing number of failures could be enumerated wherein the structures contain all the prerequisites necessary under the Rich hypothesis. If the hypothesis is correct, it must satisfactorily explain such failures. An analysis of all of the data available at the present time convinces me that no one theory can explain both the producing and the non-producing areas in Kansas. I believe that the time of folding, the presence or absence of local source beds, and the presence of unconformities and overlaps are far more important factors in the local accumulation of oil, than the postulation that this oil has migrated from the Ouachita geosyncline and has been carried northward 350 miles through Ordovician carrier beds, finally to accumulate throughout Kansas either in Ordovician reservoirs, or to migrate upward through unproved fissures into superjacent Pennsylvanian formations. An argument against this upward migration of oil is that within many Pennsylvanian producing areas tests have been drilled into the underlying Ordovician carrier beds without finding

[10] J. V. Howell, "Map Showing the Areal Geology of the Pre-Chattanooga Surface in Northeastern Kansas," *Guide Book, Sixth Annual Field Conference of the Kansas Geological Society* (August, 1932).

even a showing of oil in these lower horizons. Though most of the oil might be flushed out, is it not reasonable to expect that at least some small evidence of the original oil would still remain in the Ordovician beds?

Dr. Rich has painstakingly considered many of the details of Kansas geology, but unfortunately he has not discussed all the facts. This criticism is offered in the friendliest spirit. For the author's ability I have the highest regard. But I do not believe that oil has migrated into Kansas from the Ouachita geosyncline, nor do I believe that commercial quantities are lacking north of his "Central Kansas arch." The evidence in each case is inconclusive. However, such contributions as this cause geologists to consider their major problems. If the discussion which this paper will provoke helps to crystallize their ideas, and possibly bring us all a little closer to a solution of the problems here existent in Kansas, it will have served well its purpose.

AUTHOR'S REPLY TO DISCUSSIONS

Edson, Howell, and Folger have directed severe criticisms toward the map of "Pre-Mississippian Structure and Areal Geology" shown on Figure 1.

Their suggestions and criticisms were carefully considered during the preparation of the map, and their assistance in interpreting some of the doubtful logs and in checking all of them has already been acknowledged.

The map as printed is defended for the following reasons:

1. For the purposes of the discussion such a map, though imperfect, was essential.

2. McClellan's map for the eastern part of the state was lacking in detail. After a residence of 12 years in that part of the state, the writer possessed information and logs sufficient for the addition of considerable detail to McClellan's map. Some of this, having been obtained at first hand, he had reason to believe was more complete than was available to the stratigraphers mentioned in the foregoing discussions.

3. The only other map published to date—that by Howell, referred to in Folger's discussion—was totally unsuited for use for the following reasons: (a) the area of pre-Chattanooga uplift and Arbuckle "outcrop" in Lyon County and the two areas in Greenwood County had been omitted from that map, it being explained that for economic reasons it was not desirable to call attention to those areas at the time the map was published; (b) the most prominent northwest trend shown on Howell's map—the one extending across Franklin County into northwestern Osage County—included within the area mapped as Arbuckle and Simpson three of the four deep wells in Franklin County, all four of which, as my critics will agree, have "Viola" or "probably Viola" beneath the Chattanooga. To stretch a northwest-trending area of Simpson and Arbuckle across Franklin County from the Arbuckle area in extreme eastern Kansas to those in Osage County seemed, in view of the foregoing, to be entirely unwarranted.

4. Within 4 miles southeast of the two wells which define the Arbuckle area in Lyon County are two others which all agree in correlating as "Viola." Certainly no northwest trend is indicated there.

5. The deep wells in eastern Kansas are so scattered that, in view of the conditions described in the two preceding paragraphs, it seemed much wiser to outline the areas of the various pre-Chattanooga formations on the basis of the evidence furnished by the logs of the wells, without prejudice as to

structural trends, than to connect widely separated uplifts by unknown highs along assumed trends. There will be time enough to connect these areas when the necessary well data become available.

6. In no case where sample evidence was available have Edson, Howell, and Folger's correlations been disregarded in the preparation of the map. In fact, in only a few cases, mainly in the extreme eastern part of the area, have the writer's correlations been used in preference to theirs where there was disagreement, and those differences of interpretation had no appreciable effect on the general features of the map except to extend the Simpson area in Anderson and Linn counties and to separate the two Arbuckle areas in Osage County. In the latter area the correlations were not unanimous among my critics.

7. As to the central and western parts of the map, taken from McClellan, developments since McClellan's publication in 1930 have made possible the addition of details, but those details are in the confidential files of the oil companies. The broader features which were needed for the discussion in the present paper are believed to be sufficiently accurate for the purpose, and until those possessing the detailed and confidential information on which a better map can be based are able to release it, there seems to be nothing to do but to use the best map available.

In paragraph 3 of his discussion, Folger says, after referring to the maps in the confidential files of the oil companies: ". . . in general these agree that the dominant structural trend of the older structural axes in Kansas is northwest-southeast . . . Dr. Rich admittedly has disregarded these pre-existing structural features . . . . As a result his contact lines, east of the Granite ridge, are held to be erroneous."

The following major structural features shown in Figure 1 could be interpreted as trending northwest-southeast: the Central Kansas arch as a whole; the subdivisions of that arch north and south of the Harvey-Reno County basin; and the line of Simpson-Arbuckle pre-Chattanooga highs extending northwestward across Greenwood County. Besides, the Central Kansas arch was referred to in the text as a broad, compound geanticlinal uplift. One is led to wonder what may be the reason for the repeated assertion that known trends have been disregarded and wherein the ideas as to structure expressed in the paper are "diametrically opposed" (Edson, paragraph 2) to those generally held. The only northwest trends known to the writer or pointed out to him by his critics which are not shown on Figure 1 are: (a) the Franklin-Osage County trend shown on Howell's map, for the omission of which the reason has already been given; and (b) subordinate trends on the major Central Kansas arch which have been worked out since McClellan's map was made and whose details are in the confidential files already referred to.

In reply to the discussion by Mrs. Edson:

Paragraph 1.—Has Mrs. Edson confused areal distribution with elevation?

Paragraph 3.—Would the four principal structural features mentioned, namely, the Central Kansas arch, the Dodge City basin, the North Kansas basin, and the Ozark monocline be changed by any slight inaccuracies in Figure 1?

Paragraph 4.—As was carefully explained in the paper, the term "Central Kansas arch" was introduced as an inclusive term to embrace various units,

to one of which Morgan had given the name "Central Kansas uplift." There was no thought of superseding his term for that particular part of the arch, and the usage was clearly set out on Figure 2.

Paragraph 5.—A careful reading of the original statement is requested. It did not seem necessary in a general statement about submergence to point out that the top of a hill (Granite ridge) would be submerged later than its base.

In reply to the discussion by Howell:

Paragraph 3.—There is no doubt about the presence of rather strong post-Pennsylvanian northwest trends in eastern Kansas which are revealed by the surface structure of the Pennsylvanian rocks. Subsurface maps in which the various formations are contoured on the basis of *elevation* would, of course, show these trends in all formations down to the lowest. The query is raised whether Howell has not confused pre-Chattanooga trends with trends shown by *present elevations* of the various formations. In deciding whether or not the trends shown in the Pennsylvanian rocks represent renewed uplift on pre-Mississippian trends, the age of the formation encountered in each well beneath the Chattanooga can be the only guide. It has been pointed out in a preceding paragraph that the evidence from the available wells does not clearly indicate such a trend except in Greenwood County.

Paragraph 4.—Reversal of water movement is to be expected because in post-Pennsylvanian times the Ozark region was uplifted and the rocks in the area under discussion on its western flank were tilted westward, bevelled over the uplift, and exposed to the inflow of artesian water.

Paragraph 5 (last half).—One of the postulates of the hypothesis here outlined is that the oil migrated mainly at an early date and, in the case of the Pennsylvanian sands, that it became isolated in them while, later, the waters in the more pervious carrier beds below became modified as a result of contamination from the surface due to artesian conditions brought about subsequent to the oil migration. One would, therefore, expect the lower waters now to be different from those in the sands above.

As to the Chattanooga shale as a cover: where exposed it is brittle and highly jointed, especially in the more organic parts which, however, make up a variable proportion of its whole thickness. One would expect, therefore, that it might locally show all gradations from high perviousness to a perfect seal.

Paragraph 9.—Howell is in error in listing southwestern Kansas among areas which had been ruled out as potential producers. The Dodge City basin was repeatedly mentioned as a promising region.

In reply to discussion by Folger:

Paragraphs 4 and 5.—The importance of time of folding and of several features of unconformities is no less under the theory of oil migration here outlined than under others. The domes in the theoretically favorable areas which have proved disappointing should ultimately yield information which will aid in solving the problems relating to the origin of the oil and the reasons why it has accumulated in one place rather than another. It does not seem that the mere presence of such barren areas can be taken as evidence for or against any theory until the details of occurrence are studied. Meanwhile, the foregoing paper will have served one of its main purposes if the possibility of long-distance migration from the south is given due consideration in their study.

If the working hypothesis outlined in this paper is correct, certain results may be expected from the drilling of the admittedly inadequately tested Dodge City and North Kansas basins. In the case of the former, much oil should ultimately be found; in the case of the latter, little if any. It will be interesting to watch the results. Certainly no one would be more pleased than the writer if oil in important quantities were to be found in the North Kansas basin. Its discovery might eliminate a working hypothesis, but the function of a working hypothesis is to guide investigation, not to serve as an object of adoration.

JOHN L. RICH

May 20, 1933

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 7 (JULY, 1933), PP. 816-826, 4 FIGS.

DRISCOLL POOL, DUVAL COUNTY, TEXAS[1]

I. R. SHELDON[2]
San Antonio, Texas

ABSTRACT

The Driscoll pool is in central Duval County in southwest Texas. The surface is mantled by caliche and gravels of Recent age which makes surface geology unreliable. Sands and clays of the Reynosa or Lower Lissie formation of Pliocene age make up the surface exposures. Tests drilled in the area have penetrated Miocene, Oligocene, and as deep into the Eocene as the Cook Mountain formation. Production in the Driscoll pool is coming from the Oakville, Frio, and Fayette sands. Oil from the Fayette is 23°Bé. gravity of Mirando quality. The present three wells will produce approximately 500,000 barrels of oil, or a per-acre yield of 16,500 barrels. The pool should ultimately cover 640 acres. The structure is a sand lens controlled by folding. The Government Wells, Mirando, Pettus, and Yegua sands have not been tested but should be found in the area above 4,500 feet.

ACKNOWLEDGMENT

Helpful criticism and suggestions have been given by several members of the San Antonio Geological Society, including Thomas R. Banks, Thornton Davis, Thomas W. Calliham, Al. Ferrando, and Ed. W. Owen.

LOCATION

The Driscoll Ranch is in the south-central part of Duval County, about 8 miles from the south and 9 miles from the west boundary. It consists of 53,000 acres in a solid block, extending 10 miles north and 9 miles east to within 2 miles of the settlement of Sweden. No public roads and few trails cross the ranch; a large part can be reached only by walking or on horseback.

CLIMATE

Duval County is in the semi-arid part of southwest Texas. The rainfall is between 20 and 25 inches per year, but most of it falls in the winter months and in sudden violent storms. Six months periods without rain are usual. The temperature ranges from freezing in winter to 120° F. in summer, but the dry atmosphere and constant breeze make most of the year comfortable.

[1] Read before the San Antonio Section February 17–18, 1933, and presented by title before the Association at the Houston meeting, March 24, 1933.

[2] Consulting geologist, 1623 Smith-Young Tower.

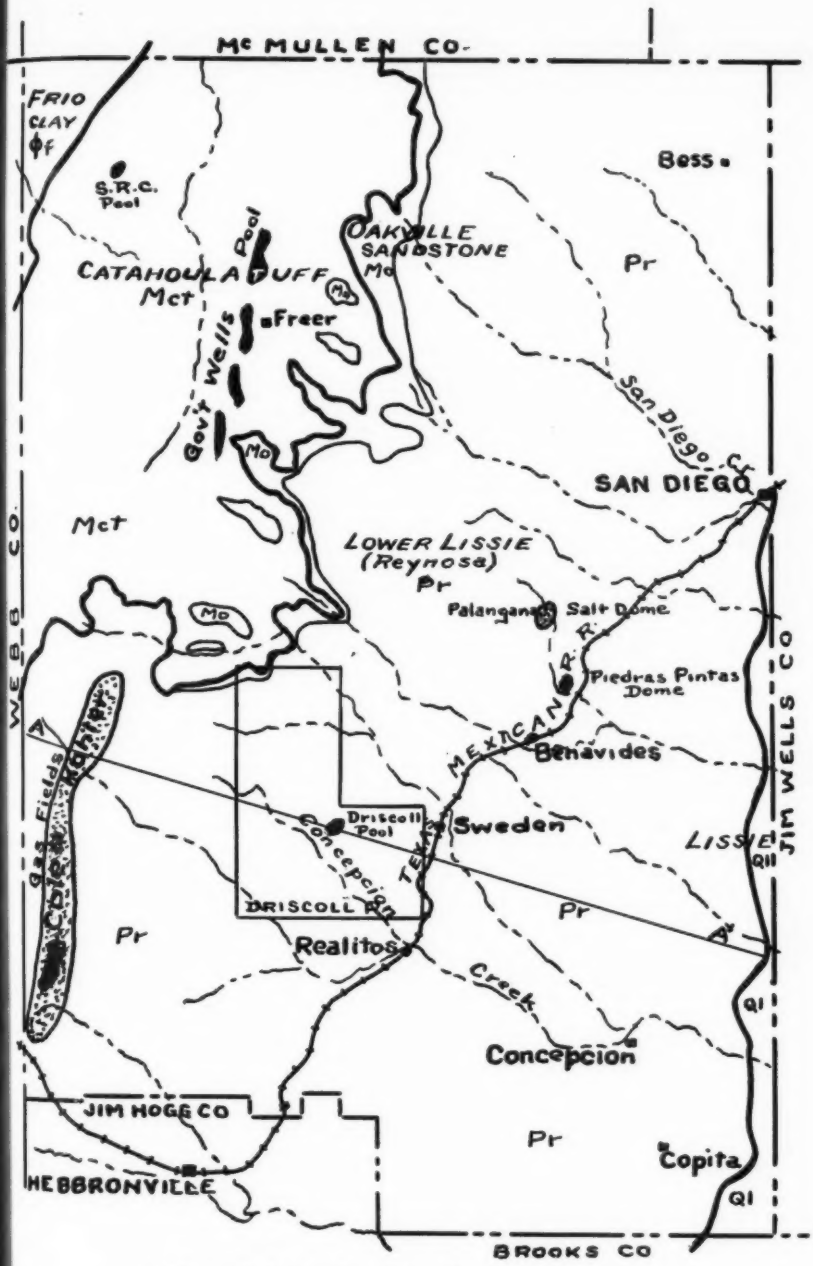

FIG. 1.—Regional surface geology, Duval County, Texas. Section *AA'* shown in Figure 2.

TOPOGRAPHY

The entire ranch is rolling, with about 200 feet of relief. The highest elevation is over 600 feet in the northwest and the low point is about 400 feet in the southeast part of the ranch. There are no permanent streams, but the dry creek beds are about 100 feet below the tops of the hills. Rosita Creek drains the north part of the ranch and Concepcion Creek the south. This is the only part of southwest Texas that has not been mapped by any branch of the government and no topographic maps of the area are available.

The average slope of the area is 8 feet to the mile southeast. The hills are formed of more resistant beds in the soft Reynosa formation. This dips gently southeast and consequently the surface is divided into a series of low, roughly parallel sloping plains with the steeper slopes to the northwest. These cuestas are cut by creeks and form rounded hills.

VEGETATION

The entire ranch is covered with a thick growth of thorns and brush characteristic of southwest Texas. Elm, hackberry, mesquite, Brazilwood, mahogany, yucca, Spanish dagger, and many varieties of cactus make up the brush. The valleys are green and the trees grow to a height of about 30 feet.

SURFACE GEOLOGY

The surface of the Driscoll Ranch is covered by the Reynosa formation. This material is thought to be of comparatively recent age and to lie as a mantle unconformably over rocks of Pleistocene and Pliocene age. The Reynosa is characterized by white or pinkish porous caliche limestone generally without form and lenticular. This is interbedded with pink, brown, and gray argillaceous sands. A small area in the northwest corner of the ranch exposes the underlying Oakville sandstone and its contact with the Catahoula tuff.

An attempt has been made to map the surface formations. This was found to be of no value except in the areas where the hills are covered with red sandy material. This sand is a lower Lissie member and appears to reflect areas of uplift. Where it is found free from caliche and gravel it can be followed, but generally conforms to the topography. The Driscoll pool is located on one of these red sand hills.

The contact of Oakville and Catahoula shows a definite eastward bend which is important. The axis of this bend or fold plunges from northwest to southeast across the ranch and indicates a zone or belt of country favorable for the accumulation of oil and gas.

SUBSURFACE GEOLOGY

The geologic column for the Driscoll pool is shown in Table I.

These formations have a regional dip southeast ranging from 120 feet per mile for the oldest or lowest to 20 feet per mile for the youngest.

Subsurface correlation can be made from well logs only where the well has been carefully drilled and systematic cuttings have been caught. No definite limestones or markers occur within the geologic

TABLE I

FORMATIONS IN DRISCOLL POOL

Age	*Formation*	*Depth in Feet* *Top*	*Bottom*	*Thickness in Feet*	*Producing Sands*
Recent	Caliche and gravel	0	80		
Pliocene	Lissie (Reynosa)	0	460	460	
	Lagarto	Not recognized in well logs			
Miocene	Oakville	460	770	310	Oakville
	Catahoula tuff	770	1,770	1,000	
Oligocene	Frio	1,770	2,800	1,030	Saxet, Refugio
Eocene	Jackson				
	Fayette member	2,800	3,080	280	Cole, Driscoll
	McElroy member	3,080	3,810	730	Government Wells Mirando
	Diboll member	3,810	3,950	140	
	"Cockfield" zone	3,950	4,300	350	Pettus, Jacob
	Yegua	4,300	4,700	400	Tuleta, Conroe
	Cook Mountain	4,700			Jennings

column and correlations must be made almost entirely on sands and sandy shale. A microscopic examination of the cuttings by a paleontologist and frequent coring are almost indispensable to the identification of formations and the location of producing horizons.

The Oakville sand is shallow in this area and contains water and in some places gas. It furnishes water for many of the windmills and a careful study of their records reveals possible structure. In many of these wells gas has been the first indication of structure and has led to deeper drilling. The Driscoll pool was discovered in this manner. It is possible that shallow core drilling to this Oakville horizon would be valuable.

The top of the Fayette member of the Jackson formation is the best known horizon in southwest Texas. All drillers and geologists are trained to look for it and usually record it on well logs. It is marked by a sudden change from the Frio gray sand and shales and gumbos to dark lignitic sandy shales which are replaced by the hard top of the Cole sand. This sand is missed in many places, or it is replaced by

sandy shale, but careful drilling will find this marker. The producing horizon in the Driscoll pool is a lenticular sand which is found about 100 feet below the top of the Fayette member and the so-called Cole sand of the Government Wells area is believed to correlate with it.

A subsurface map of this part of Duval County has been prepared from well logs and all data available. This map reveals an eastward

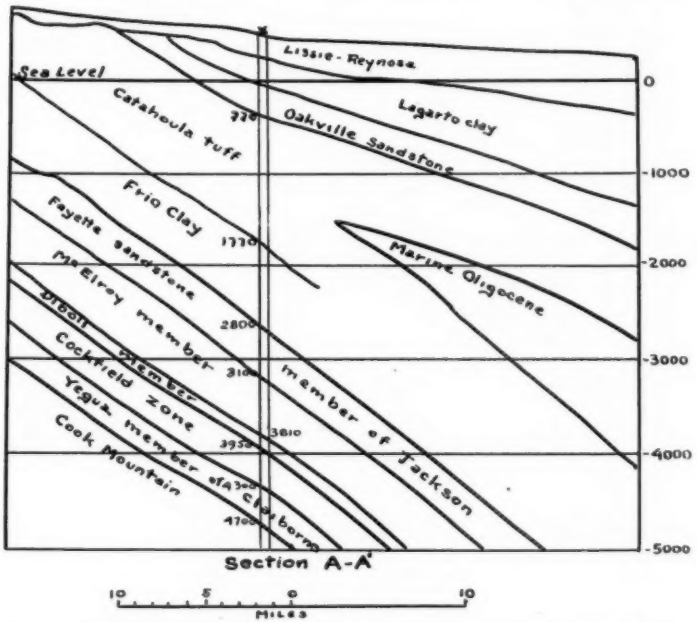

FIG. 2.—Generalized cross section, Duval County, Texas. Vertical scale in feet.

swing or bulge in the contours on the top of the Fayette member of the Jackson formation. These swings occur around each pool producing along the west side of the county and their axes are accepted as the trends of the producing areas. The axes of the individual pools are at right angles to these trends. The trend southeast from the Kohler pool passes through the Driscoll pool.

The Cole sand is the producing sand near the top of the Fayette member of the Jackson formation. It produces gas in large quantities all along the Reynosa escarpment and in spots is productive of oil. This member is known to contain several lenticular sands and a careful study of the individual areas must be made before it is known

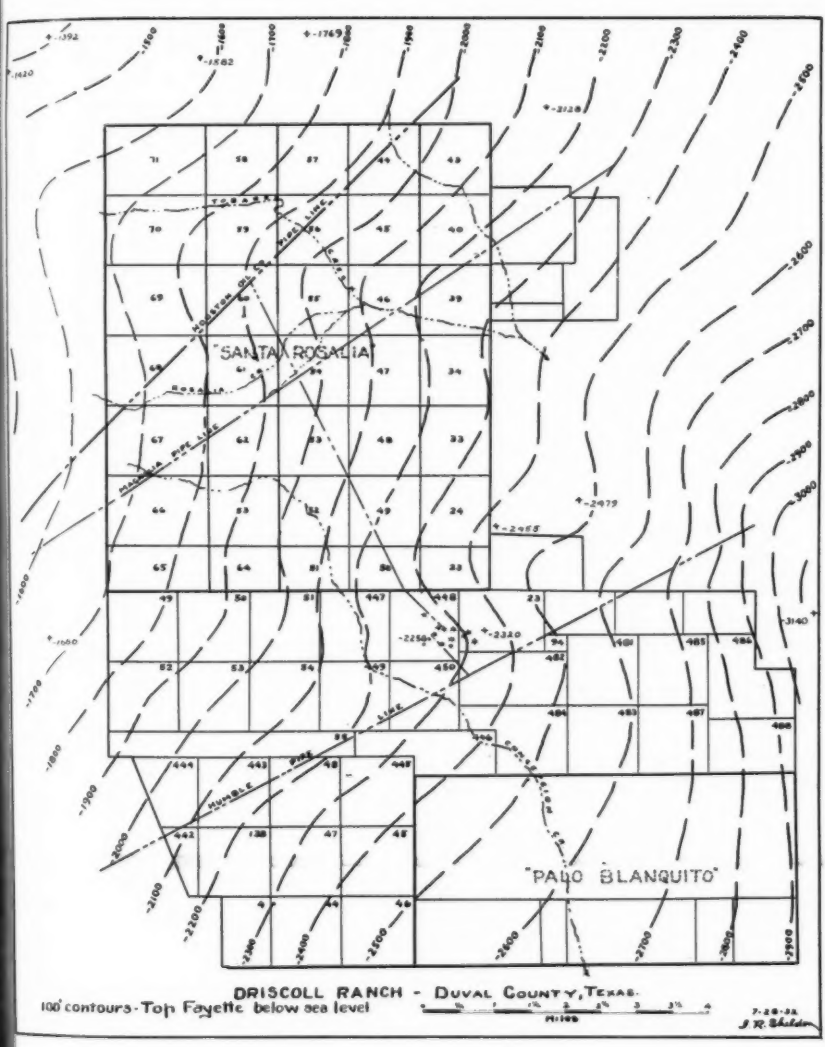

FIG. 3.—Subsurface geology of Driscoll Ranch, Duval County, Texas. Contour interval, 100 feet, on top of Fayette.

whether or not the production is coming from the top of the formation or from one of its other sands. Just below the Fayette is the McElroy member. It contains the Government Wells sand, which is about 780 feet below the Cole sand, and the Mirando sand, which is about 170 feet lower. These two sands produce most of the oil in the Laredo district. The Pettus sand is about 550 feet below the Mirando sand. It is in the transition zone between the Jackson and Claiborne forma-

TABLE II
RECORD OF WELLS IN DRISCOLL POOL

Well	*Completed*			*Depth in Feet*	*Elev. in Feet*	*Datum on Top of Producing Sand in Feet below Sea-Level*	*Thickness of Sand in Feet*	*Initial Gas Production (Million Cubic Feet)*
	Month	*Day*	*Year*					
1			1908	608	514	36		3
2						No record		
3			1908	528	545	17	28	3
4			1908	517	544	27	12	6
5			1909	517	546	29	10	4
6			1909	532	531	20	12	2
7	10	9	27	2,468	531	−1,916	20	15
8	12	22	27	2,441	532	−1,905	4	50
9	2	29	28	2,988	529	−2,406	40	Oil and water
10	2	6	28	2,480	546	−1,931	3	30
11	4	21	28	2,461	534	−1,923	4	60
11	2	1	30	Deepened to 2,900-foot sand and made oil well				
12	8	25	28	2,905	532	−2,351	15	40
13				2,475	571	−1,897	7	40
14	2	20	29	2,894	550	−2,336	4½	875 bbls. oil
15	4	30	29	2,899	557	−2,336	3	590 bbls. oil
16	6	25	29	2,955	553	−2,342	17	75

tions, about 30 feet below the bottom of the Diboll member of the Jackson, and is recognized by the presence of *Nonieneonella* forams. This transition zone is known in South Texas as the Cockfield zone. The Yegua member of the Claiborne has not been reached in any of the tests near the Driscoll Ranch. The top of this formation contains the Tuleta or Conroe sand and should be found less than 300 feet below the Pettus sand.

PRODUCTION

The Driscoll pool is the only producing area on the Driscoll Ranch near Sweden. This pool was discovered in 1908 by the fee owner, Robert Driscoll, by gas found in water wells. It has never been leased and all of the development has been directly under the supervision of the owners.

A detailed record of the wells is shown in Table II.

The lower sand was found in No. 9, but contained too much water to be a commercial well. Well No. 12 reached the sand in August, 1928, but yielded only gas. In February, 1929, well No. 14 proved the presence of oil by flowing 875 barrels per day. Well No. 15 soon proved

TABLE III

MONTHLY PIPE-LINE RUNS, DRISCOLL POOL (IN BARRELS)

	1929	*1930*	*1931*	*1932*	
January	—	4,966	11,122	4,434	
February	—	6,332	7,733	6,294	
March	3,045	5,363	8,158	7,473	
April	3,815	9,987	7,943	6,494	
May	12,767	12,058	7,992	5,963	
June	6,920	12,409	6,866	4,759	
July	7,980	11,805	5,267	5,000	
August	6,919	11,108	5,088	5,500	
September	6,930	9,578	5,909	5,391	
October	6,709	8,984	6,894	4,515	
November	4,221	7,384	5,754	6,450	
December	6,186	5,458	4,217	6,386	
TOTAL	64,842	104,432	82,943	68,759	320,976

the presence of a pool by flowing 590 barrels per day. No. 11 was then deepened to this sand and yielded commercial production, but no record was kept of the deepening. These three wells have produced all of the oil from the pool and are still producing.

TABLE IV

ESTIMATED FUTURE PRODUCTION, DRISCOLL POOL (IN BARRELS)

Total for 1933	57,600
1934	43,800
1935	29,584
1936	18,504
1937	12,000
1938	7,800
1939	5,100
Total future	174,388

PER-ACRE YIELD

Total production through December, 1932	320,976
Estimated future production	174,388
Grand total for three wells	495,364
On the assumption of a drainage of 10 acres per well, or a total drainage of 30 acres, the yield per acre will be (ultimate in barrels)	16,500

All of the wells were drilled under the direction of Robert Driscoll and his sister, Mrs. Clara Driscoll Sevier, by Ed. Meins as superintendent and Bob Evans as head driller. The Houston Pipe Line Company is connected with the gas wells and the Humble Pipe Line Company is taking the oil. The oil is of the regular Mirando quality of crude. The gas is being sold at the rate of 500,000 cubic feet per day.

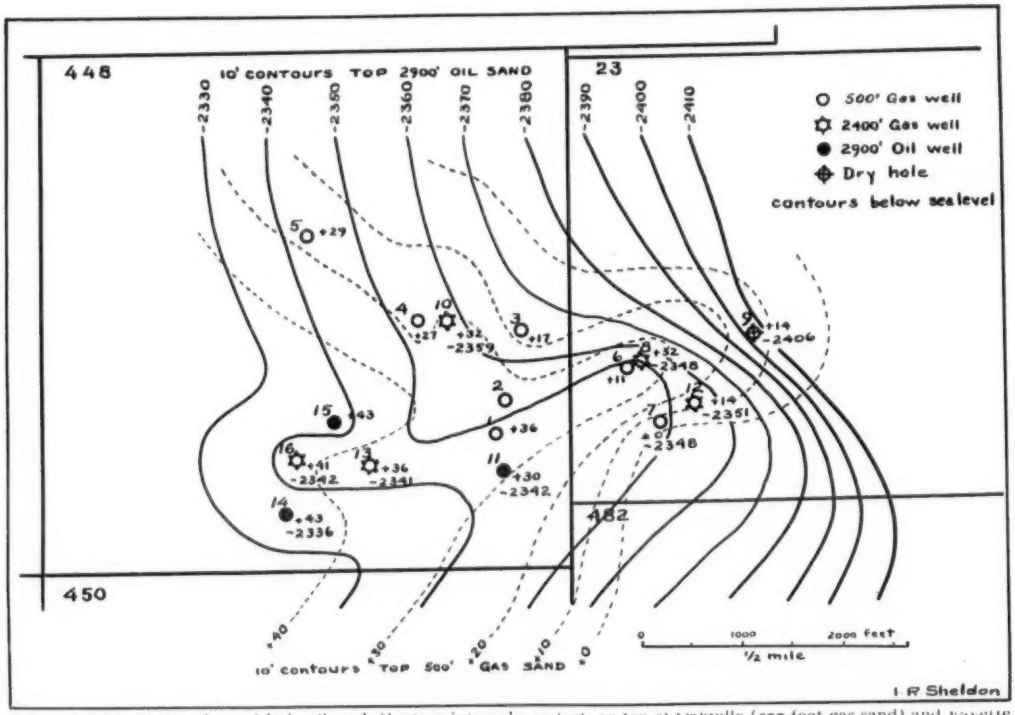

FIG. 4.—Subsurface geology of Driscoll pool. Contour intervals, 10 feet, on top of Oakville (500-foot gas sand) and Fayette (2,900-foot oil sand), below sea-level.

FIG. 4.—Subsurface geology of Driscoll pool. Contour intervals, 10 feet, on top of Oakville (500-foot gas sand) and Fayette (2,900-foot oil sand), below sea-level.

FUTURE PRODUCTION

Future production from these three wells can be plotted with considerable certainty. The wells have always flowed to capacity and no artificial means have been employed to increase their production. At the present time they are making about 100 barrels of water per day, but this does not seem to be increasing and has not interfered with their flowing.

The estimated future production based on the curve for 1930, 1931, and 1932 is shown in Table IV.

PRODUCTIVE ACREAGE

A study of the pool in Sections 23 and 448 shows that the present productive area is 4,000 feet east and west and 2,500 feet north and south and covers approximately 240 acres. The subsurface elevations of the tops of the Oakville, Frio, and Fayette sands have been contoured. Figure 4 shows the subsurface elevations and contours on the tops of the Oakville and Fayette sands. The Frio sand contours as a sand lens and is thought to be of local significance.

The Oakville sand is about 500 feet deep and contains fresh or sulphur water except where gas has driven it out. It is only considered important on account of its ability to reflect structure in the lower horizons. The similarity of its structure to that of the 2,900-foot Fayette sand suggests that the folding which has caused this structure has been progressive through long periods of time.

Although this pool lies rather close to two known salt domes, there is nothing to suggest a salt-dome structure here. The map of Duval County contoured on the top of the Fayette member, a part of which is shown in Figure 1, hints that the continental shelf or neritic phase of the Jackson formation commences at the eastern edge of the Driscoll Ranch. At about this point the beds dip more sharply and the contours are therefore closer together. Salt domes of the penetration type are east of this zone. Everything about the structure here suggests that it is similar to the other producing areas in the Laredo district in that the accumulation of oil and gas is caused by a combination of sand lensing and folding. In the other fields the sand lenses out on the west side along a line trending about N. 20° E. and accumulation is found east of this line, where it crosses a broad transverse fold that has a northwest-southeast axis. The sand is thicker on the flanks, indicating that the folding was progressive during deposition. Sand conditions are fairly regular, with a general thickening eastward. On the assumption that the Driscoll pool is of this kind of structure,

it is estimated that the producing area of the lower sand will be about 640 acres.

LOWER SANDS

The Fayette member is the upper producing horizon of the Laredo district and is the least productive. The Government Wells sand, which lies 700 feet below the top of the Fayette in the McElroy member, is the most productive, and the Mirando sand, 200 feet still lower, is nearly as good. The Pettus sand, which lies 500 feet below the Mirando sand in the transition zone between the Jackson and Claiborne formations, does not produce in Duval County, but is found on both sides of it in Webb and McMullen counties.

The chances of finding these lower sands in the Driscoll area are good. The Fayette and Government Wells sands are found closely associated in the Government Wells pool and in other parts of the Laredo district. In the well drilled by Calliham *et al.* just northeast of the Driscoll Ranch and about 8 miles north of the Driscoll pool all of these sands were encountered. The Pettus sand was about 1,250 feet below the Driscoll sand, which indicates a slight thinning of the interval between the horizons in this area.

A deep test in the Driscoll pool should locate the lower sands as follows: Government Wells sand, 3,500; Mirando sand, 3,700; Pettus sand, 4,050; and Yegua sand, 4,225.

This area lies close to the same subsurface contour as Tuleta in Bee County and just up the dip from the neritic phase of the Jackson formation. This means that the lower formations probably thicken in a relatively short distance southeast and that this belt of country is especially favorable for oil accumulation.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 7 (JULY, 1933), PP. 827-842, 5 FIGS.

PRESERVATION OF OIL DURING EROSION OF RESERVOIR ROCKS[1]

GEO. EDWIN DORSEY[2]
Dallas, Texas

ABSTRACT

Some of the most prolific oil fields in the United States are productive from porous rocks below unconformities of major importance. The oil is found trapped at the unconformity in porous rocks of pre-unconformity age sealed by non-porous rocks of post-unconformity age.

If it is assumed that the oil formed and accumulated in the primary uplifts, it becomes necessary to explain how this oil was preserved during the long erosional interval when even the reservoir rocks were exposed and eroded. This problem is avoided if it be assumed that the oil was either not formed until after the deposition of the post-unconformity impervious rocks, or was introduced into the pre-unconformity reservoir rocks in post-unconformity time along the unconformity or in some other manner.

It is believed that an impartial survey of the geological data affords no evidence either that the oil was formed in post-unconformity time or was introduced at a later date. Comparisons of the rock sections containing the unconformities with sections of identical age and lithology without great unconformities show the oil occurrences in both to be much alike. It seems just as reasonable, therefore, to assume the formation of oil to have occurred by the time the folding began which enabled accumulation to start.

If this belief is accepted the problem of preserving the oil during exposure and erosion of its reservoir rocks must be squarely faced. The writer points out a protective mechanism. The action of gravity alone will protect the oil because (1) by definition an uplift lies above its surroundings, is an area of run-off of surface waters, and the exposed porous rocks constitute areas of intake, and (2) the underground fluid level of a major uplift never lies at the surface of erosion, but at appreciable depths below the surface. This protective process is latent in all uplifts undergoing erosion. Other factors necessary before this potentially protective mechanism becomes effective are (1) depth to underground fluid level when submergence occurs, (2) rate of deposition of impervious post-unconformity beds compared to rise of oil level toward eroded ends of reservoir rocks, (3) efficacy of post-unconformity sediments as impervious seals.

INTRODUCTION

Some of the most prolific oil fields in the United States are productive from porous rocks below unconformities of major importance. The oil is found trapped at the unconformity in porous rocks of pre-unconformity age sealed by non-porous rocks of post-unconformity age. Conspicuous examples in the Mid-Continent are Augusta-Eldorado in Kansas; Oklahoma City, Garber, and Cushing in Oklahoma; and the East Texas field.

Although there is a diversity in the ages of the rocks involved and

[1] Read before the Association at the Houston meeting, March 24, 1933. Manuscript received, April 11, 1933.

[2] Chief geologist, Magnolia Petroleum Company.

in details of the structures, these fields are alike in having three common characteristics: (1) the presence of a major unconformity which represents a time of erosion and truncation of the older oil-bearing beds; (2) the presence now of extremely large quantities of oil at what were once the outcrops of the pre-unconformity reservoir rocks; (3) a covering of impervious post-unconformity rocks across the truncated ends of the pre-unconformity oil-bearing strata.

If the oil now found under these conditions were present as oil during the truncation of the uplifts and exposure of the reservoir rocks, some natural process must have operated to protect this oil and save it from dissipation during the erosion period. Judging by the number of important oil fields of this type, this preservative process was not a rare phenomenon. Instead, the factors responsible for the preservation of the oil appear to be latent in any geological cycle involving uplift and truncation.

Had there been no such protective process in operation, the oil now found could not have been present as oil in the pre-unconformity series during erosion and it must either have formed subsequent to the period of erosion or have been introduced from outside sources in post-unconformity time.

That the present occurrence of oil at unconformities which exposed the reservoir rocks is a problem which has interested geologists is evidenced by papers such as those by Rich,[3] and is apparent in the discussion of these papers. Rich ascribes the occurrence of the oil to lateral migration along the unconformity from sources more or less remote into the rocks where it is now found. Gardner, Wilson, and Howard,[4] who have discussed Rich's papers in print, and many geologists with whom the writer considered the problem, believe the oil must have formed and accumulated subsequent to the erosional period represented by the unconformity chiefly because otherwise the oil would have escaped.

The following statement occurs in one of Rich's[5] papers.

> As the major oil accumulations are found at the unconformity below the Pennsylvanian rocks or in them, it is obvious that the oil accumulation was a post-Pennsylvanian event.

[3] John L. Rich, "Function of Carrier Beds in Long-Distance Migration of Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 8 (August, 1931), p. 911–24; "Source and Date of Accumulation of Oil in Granite Ridge Pools of Kansas and Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 12 (December, 1931), pp. 1431–52; "Discussion," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 3 (March, 1932), pp. 260–66.

[4] John L. Rich, *ibid.*

[5] John L. Rich, "Source and Date of Accumulation of Oil in Granite Ridge Pools of Kansas and Oklahoma," *Bull. Amer. Assoc. Petrol Geol.*, Vol. 15, No. 12 (December, 1931), p. 1440.

Here the only basis for the use of the word "obvious" in referring to oil in the pre-unconformity rocks is the belief that the oil, if formed and accumulated prior to erosion, would have escaped during the erosional interval. Apparently the post-unconformity dating of the formation and accumulation of the oil is accepted more as a possible way out of the difficulty than because of indisputable geological evidence that the oil did actually form and accumulate in the reservoir rocks in post-unconformity time.

There is no direct geological evidence indicating that the oil did form and accumulate subsequent to the unconformity. From the geological evidence it appears more reasonable to believe the oil had formed and had accumulated in the uplift prior to erosion and exposure of the reservoir rocks. The present purpose of the writer is to call attention to a geological process which would almost inevitably occur during an erosional period and which would result in preserving the oil content of the rocks during erosion of the latter, thus permitting its subsequent accumulation in post-unconformity time at the unconformity, in precisely the manner in which the oil is now found.

TIME OF FORMATION OF OIL

There is no definite rock evidence which indicates the precise geological age assignable to the formation of oil from the source materials. There are no geological criteria to indicate that "formation of petroleum" may be ascribed a rôle as a stratigraphic marker. All of those papers which correlate oil formation with large or small orogenic periods are theoretical in nature and invariably call forth opposing views which in themselves are also controversial. The geological record is not clear on this point. So far as the rock record is concerned, the oil may begin to be formed soon after deposition, or at a very much later time.

This lack of definite rock evidence may be illustrated by two specific examples. If it is assumed that the Ordovician oil at Oklahoma City formed and accumulated in post-unconformity time, a period from early Pennsylvanian to Recent is involved. At the surface and east from the Oklahoma City field there are exposed progressively downward, in the order named, lower Permian and Pennsylvanian down to post-Cherokee rocks, the latter in the Tulsa area, where Ordovician oil has been found. In this rock section exposed between Oklahoma City and Tulsa there are no great unconformities or other evidence of the operation of earth forces which might mark a definite time of formation of oil. This section accounts for the post-Cherokee-lower Permian part of the early Pennsylvanian to Recent interval. Therefore,

if a definite period of oil formation occurred subsequent to the Oklahoma City unconformity it must be ascribed to a time later than lower Permian, that is, later than the surface beds at Oklahoma City. When such an event is ascribed to the Permian (Appalachian revolution), or to any other geological epoch from lower Permian to Recent, the evidence on which such conclusions are based is inferential and largely theoretical; hence the highly controversial nature of papers such as those by Rich.[6]

The same indefiniteness in age is apparent if a special period of oil formation is assumed to be responsible for the East Texas oil field. The Woodbine sand produces prolifically from the Mexia-Powell fault fields where there is no unconformity present in the strata, from Woodbine through Navarro, comparable with that which truncated the ends of the Woodbine sand and Eagle Ford shale on the west side of the Sabine uplift. If this unconformity represents an Austin erosional period on the Sabine uplift, the same time interval witnessed thick chalk deposition in the Mexia-Powell fault area. If the Woodbine oil resulted from a definite time of formation of oil which occurred after the Austin erosional period on the Sabine uplift, it is to be dated as occurring at some time between late Austin and Recent. The rock section which represents this time gives no definite or convincing evidence that such a period occurred.

To be sure, in the post-lower Permian to Recent time interval in Oklahoma three major orogenies occurred, and in the post-late Austin to Recent interval in Texas two major orogenies convulsed the earth. These are clearly to be seen in the rock record. But the theory that to such orogenies or to smaller ones the time of the formation of oil is to be ascribed is dependent on inferences regarding the requisites for oil formation which have not been proved and on which the rock record at this time is neither definite nor conclusive.

Because of the unsatisfactory geological evidence on which rest the theories that oil is formed at definite periods in earth history, it seems more reasonable to believe that the oil forms at any time subsequent to the deposition of oil-bearing sediments; that this oil will enter the reservoir rocks as a result of normal processes incident to burial and consolidation in a zone of sedimentation; that the accumulation and concentration of the oil will occur under the action of gravity, whenever the rocks are so distorted as to make what are now called favorable structures. Credence is given such a series of events by the fact that nothing is introduced that requires special, catastrophic agencies for the formation of oil, and by the further

[6] *Op. cit.*

fact that the sedimentary record, though lacking any conspicuous evidence that a precise time of formation of petroleum did occur, does reveal a more or less rhythmic recurrence of the same set of sedimentary conditions, with an attendant rhythmic recurrence of oil deposits. The belief that oil formation is a normal and incidental feature of a geologic cycle in which potential oil-producing sediments are involved seems to have much the greater amount of credible evidence in its favor.

THE PRESERVATIVE PROCESS

The pre-unconformity series represents a more or less complete geological cycle,—submergence, deposition, distortion, elevation,

FIG. 1.—Primary folding,—oil accumulation occurring below underground fluid level. Underground fluid level, drawn as line across strata, indicates level to which fluids will rise only in rocks which are capable of holding fluids. Obviously no free fluids will be found in non-porous, impervious strata.

erosion, and possibly partial or complete peneplanation. Such a cycle is complete in itself and would have occurred before the post-unconformity rocks were deposited. This cycle is adequate to develop oil fields of importance, as is evidenced by the actual occurrence of prolific oil fields in rocks showing precisely this sequence.

In such a geologic cycle when there has been deposition, distortion, and elevation of a series of sedimentary rocks capable of forming petroleum, by the time erosion begins to act on the uplift oil as oil may be present in the reservoir rocks. If this be true, the problem of how this oil is preserved from dissipation when the reservoir rocks themselves are cut into by erosion becomes apparent at once, and the need of an adequate preservative process arises.

It is believed that the preservation of this oil would be achieved by the operation of gravity alone, and the fundamental features of the ensuing explanation are (1) by definition, an area of uplift lies above its surroundings, is a region of run-off of surface waters, and the exposed porous rocks constitute areas of ground-water intake, and (2) the underground fluid level of a major uplift never lies at the surface of the uplift, but at appreciable depths below the surface of

erosion. Whatever fluids, oil or water, may compose the underground fluid content of exposed reservoir rocks, these fluids can not, under the action of gravity alone, flow upward to the outcrops of the reservoir rocks at the surface of the uplift.

If the pre-unconformity cycle is followed, step by step, this will

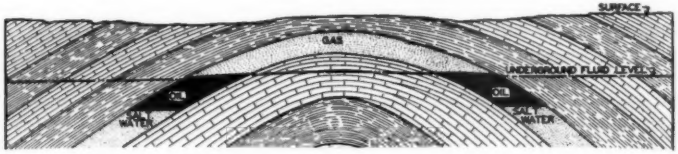

FIG. 2.—Elevation of fold, leaving oil and water at underground fluid level, but before exposure of reservoir rocks.

reveal how the action of the force of gravity operates to protect the oil from destruction. During or after deposition, forces causing folding occurred. Arches were formed which permitted the gravitational separation of the oil and water in the reservoir rocks, as shown in Figure 1.[7] Simultaneously with folding, or later, elevation occurred

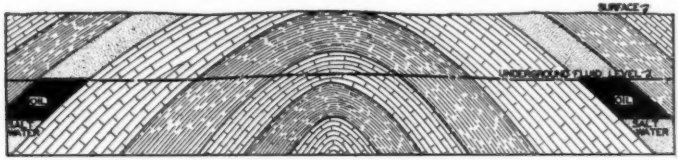

FIG. 3.—Progressive uplift, exposing and eroding reservoir rocks, oil and water remaining below surface.

which ultimately raised the rocks to a position where erosion began. The underground fluid level beneath the folded uplift remained constantly below the surface, and progressive uplift left this fluid level behind. Floating on this surface in the reservoir rocks any oil originally present must remain, as shown in Figure 2.

As the reservoir rocks rise above the normal underground fluid level, they are drained of their fluids. Ultimately, with progressive uplift, erosion will pierce the reservoir rocks, as shown in Figure 3. If there were any gas in them under pressure, it will now be free to escape. The removal of the hydrostatic head, however, would prob-

[7] The assistance of Fred E. Joekel, who prepared the illustrations, is gratefully acknowledged.

ably leave little pressure on any gas present. The oil, held back by gravitational forces, can not follow the gas. It must remain behind with the connate water at some depth below the exposed ends of its containing rocks.

Under the conditions shown in Figure 3 fluids, including oil, within the reservoir rocks would lie in a static condition, relaxed. Wagner[8] points this out. He says,

> Although oil sands and evidences of oil would undoubtedly be encountered in the event a well was located on the flank of such structure, no hydrostatic head or gas pressure would or could be present to create movement of fluid within the reservoir. Would you expect an oil field under this condition? Certain areas in the southern end of San Joaquin Valley, in the vicinity of Maricopa Flat (California), would seem to illustrate this condition very nicely. Numerous wells have encountered a thickness of oil sand on the flanks of certain structures comprising the Temblor Range uplift, although production results from such oil zones are limited to a few barrels daily which might be construed as seepage oil into the well. At points above this saturation, and presumably above the water table, the sands appear dry and the sand grains coated with asphalt. Could not this be illustrative of your contention that the oil originally gravitated downward concurrently with the falling water table, and in so doing has left portions of its constituents behind as evidence of its former position?

The Maricopa Flat area is discussed in detail by Atwill.[9]

There are doubtless other areas illustrative of the conditions pictured in Figure 3. The writer is either not familiar with these at the present time or has not sufficient detailed data regarding them to feel safe in citing them as examples.

In the Coalinga and Lost Hills fields (California), according to Wagner,[10] outcrops of the truncated reservoir rocks have been sealed by asphaltum. Here the oil is held in the outcropping formations below the water table under pressure by means of this asphaltic seal. These fields, therefore, are not examples of the oil occurrence shown in Figure 3.

The Coalinga field is described by Arnold and Anderson,[11] and the Lost Hills field by English.[12]

When the period of erosion has run its course and subsidence sets

[8] Carroll M. Wagner, personal communication.

[9] E. R. Atwill, "Truncation of Maricopa Sandstone Members, Maricopa Flat, Kern County, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 6 (June, 1931), pp. 689–96.

[10] Carroll M. Wagner, *op. cit.*

[11] Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California," *U. S. Geol. Survey Bull. 398* (1910).

[12] Walter A. English, "Geology and Petroleum Resources of Northwestern Kern County, California," *U. S. Geol. Survey Bull. 721* (1921).

in, the fluid level begins to rise relative to a given point in the rocks. The dry, uplifted, drained reservoir rocks slowly sink back into their contained fluids, as shown in Figure 4. At Oklahoma City and East Texas, the reservoir rocks happened to occupy a position in the rock section which caused them to be among the earlier rocks removed from the uplift. This meant that their eroded ends probably cropped

FIG. 4.—Early post-unconformity submergence,—time of deposition of impervious sediments, and rise of underground fluid level toward unconformity.

out fairly low on the sides of the uplifts when subsidence began; hence they would be among the first beds to be submerged and subjected to deposition under the post-unconformity sea.

With continued sinking, there would be relatively a continued rise of the oil and water level which ultimately would reach the unconformity and the eroded ends of the reservoir rocks, as shown in Figure 5. If these ends had been sufficiently sealed by post-unconformity

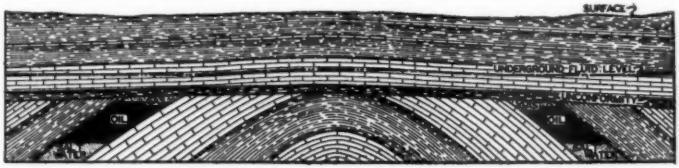

FIG. 5.—Final accumulation of oil at unconformity by sinking of unconformity below underground fluid level.

muds or other impervious material, the oil and its associated connate water could rise no farther. It would be trapped at the unconformity below impervious post-unconformity strata. These are the conditions under which it is found to-day. If the oil had reached the eroded ends of the reservoir rocks before they had been sealed, there would have been nothing to prevent the escape of the oil, and it probably would have been dissipated.

If the foregoing is a chain of events which could and did actually occur during a complete geological cycle on an uplift of the type being

considered, then it is apparent that a means of protection for any oil contained in the porous rocks of the series is provided, and is a mere incident in the orderly progression of the cycle. Although the protective process is a result primarily of (1) the action of gravity upon the fluid content of reservoir rocks which are above the elevation of the surrounding area, involved in the process also are (2) depth to underground fluid level when submergence occurs, (3) rate of deposition compared with rise of oil level toward the eroded ends of the reservoir rocks, and (4) efficacy of the post-unconformity sediments as impervious seals. The indifference of natural processes to waste, as evidenced here in the requirement that the last three factors must work together or the oil will be dissipated, has doubtless resulted in the loss of many great bodies of oil. But that all of these factors did work together at times, and comparatively frequently, may be inferred from the number of existing oil fields of this type.

In discussion of the ideas here set forth with other geologists, an objection most frequently advanced was that escape of the oil and its associated mineralized water would occur as springs through fissures at low altitudes on the flanks of the uplifts, or the oil would be flushed to lower structures.

In answer to these objections, attention is directed to two characteristics of the uplifts, (1) their slow rate of elevation, and (2) the fact that, because they are cut into so deeply, the uplifts were doubtless in areas of considerable precipitation and run-off. The very deliberate rate of uplift would afford ample time for the underground fluids to maintain the level which was stable for them. It is not likely that these fluids would suddenly be carried up to unstable levels and seek outlet by torrential discharge through lateral fissures.

If, however, the underground fluid level should lie above the floors of deep flanking canyons, the connate water or even the oil might escape as springs. Many mineral springs on the flanks of great uplifts, like Pikes Peak, doubtless derive their waters from such a source. But the fluid outlet afforded by such fissures would probably be small compared with the amount of fluid taken in on the outcrop of the porous rocks. The intake would probably be more than adequate to maintain the normal underground fluid level in spite of such leaks. Springs which never go dry must tap a source of supply which the springs' discharges are inadequate to deplete. The mineral content of waters issuing from such springs would gradually decrease. But the oil, if present, would doubtless continue to ride on the surface of the underground fluid level, and the meteoric water, because of its percolating rather than steadily flowing movement, would by-pass the oil

and sink into the mineralized water beneath it. If, however, the lateral fissures should connect directly with the oil, which lay at a higher level underground, the oil would undoubtedly drain out and reach the surface as a seep. In most cases it seems probable that the underground fluid level would lie below the bottoms of the deepest lateral topography.

Another principal objection advanced is that meteoric water taken in on the outcrop would flush the oil to lower structures. Since slow percolating movement of the meteoric water is involved, it is questionable whether water entering porous rocks in such a manner would push the oil ahead as a body or would by-pass it by forming channels through which it could slip below the lighter oil. Although it be admitted that such slow percolating movement of meteoric water could flush oil to lower flanking folds in some cases, the actual presence of tremendous amounts of oil in the pre-unconformity rocks of uplifts of the type discussed herein affords the best evidence that it was not flushed out during erosion if it be admitted that the oil now found in the pre-unconformity reservoir rocks was present in them during the erosional period.

The most formidable objection is noted by Trask,[13] who points out that during the initial stages of post-unconformity submergence, shown in Figure 4, the water beneath which deposition would be occurring should be able to flood the porous reservoir rocks, permitting the escape of any oil in the latter before the underground fluid would reach the unconformity as a result of subsidence alone. This would obviously happen unless the eroded ends of the reservoir rocks had been sufficiently clogged to prevent the entrance of water. Clogging could be caused by terrestrial deposition or by an oxidized petroliferous residue in the sands through which the oil had passed twice. Preservation of the oil in the early stages of post-unconformity submergence would depend upon a balancing between the minimum time for an effective impervious layer to be deposited over the porous ends of the reservoir rocks and the maximum time during which any clogging of the reservoir pores could hold the water out.

Wagner[14] makes the following comment:

> Coalinga, Lost Hills (California), and several other localities are distinct examples of oil retained in outcropping reservoir formation below the water table by virtue of surface seal of asphaltic material which has clogged the pores of the reservoir formation and prevented further escape even under present conditions of considerable pressure.

[13] Parker D. Trask, personal communication.

[14] Carroll M. Wagner, *op. cit.*

GEOCHEMICAL AND GEOPHYSICAL FACTORS INVOLVED

With progressive sinking below underground fluid level, the oil and water are subjected to normal hydrostatic pressure (the weight of a column of water the height of which equals the distance between the surface of the oil and the surface of the normal underground fluid level). Pressures in the unconformity oil fields are close approximations to this theoretical pressure. With increase of pressure, due to progressive sinking, there is a corresponding rise in temperature of the rocks enclosing the oil. The oil is therefore subjected to increased heat and pressure. These two factors in refinery practice result in the cracking of oil with production of gas. In the geological process there is added to the heat and pressure factors a factor which also may be of importance,—an extensive period of t'me. The earth pressures to which oil is subjected, ranging from 1,000 to 3,000 pounds, are in excess of those usual in refinery practice. The time during which the oil is subjected to these pressures is also much longer. This extra pressure and time may perhaps offset a somewhat lower temperature in the earth than that required in refinery cracking. It seems reasonable to think that oil exposed to such pressures with some elevation of temperature would, in the course of a vast period of time, undergo cracking with an attendant formation of gas. The difference between the gas found with the oil in the unconformity fields and that in the normal fields is that the oil in the former probably went through two separate periods of cracking, and the gas now found in the unconformity fields is partly or entirely the product of the second cracking.

If the only pressure on the gas originally contained in the reservoir rocks prior to truncation was hydrostatic, when the reservoir rocks were elevated above the underground fluid level this pressure would be relieved. When the reservoir rocks were ultimately pierced by erosion there could be no hydrostatic pressure on the gas. There might even be a partial vacuum. Under these circumstances the original gas would not escape until the post-unconformity subsidence had set in, when the gas would bubble off as the underground fluid level rose toward the unconformity. It is conceivable that if post-unconformity deposition were rapid enough and the post-unconformity sediments provided quickly an adequate impervious covering, or if the reservoir pores had been clogged, some of the original gas might be caught and sealed in, to mingle with gas formed by a second period of gas evolution.

The mineralization of the connate water associated with the oil in unconformity fields shows some interesting relationships. The erosional uplifts which are being considered are analogous to the Black

Hills to-day. The outcropping belts of Dakota and Lakota sands around the Black Hills are not areas of ground-water discharge, but are zones of intake. Similarly, the outcropping reservoir rocks on comparable structures during past ages should have been zones of intake of meteoric water. This water, because of its greater weight, would probably by-pass the surface covering of oil in the reservoir rocks and mingle with the connate water. In the course of a vast period of time this periodic addition of meteoric water should have the effect of noticeably lowering the mineral content of the connate water.

Such dilution actually is observed. Whitehead[15] states that the water found with the oil on the east or up-dip side of the East Texas field contains 28,000 solid parts per million, and the water on the west or down-dip side contains 65,000 parts per million. Fash[16] has evidence that there is a dilution of the water in West Texas as the large folds are approached. Dott and Ginter[17] state that the normal concentration of Ordovician waters in Oklahoma is 160,000 parts per million North from the Arbuckle Mountains the concentration of Ordovician waters increases down the dip from 10,000 parts per million to 150,000 parts per million in a distance of 14 miles. The concentration of the Ordovician waters in the Augusta-Eldorado field on the Nemaha ridge in Kansas is 20,000 parts per million. These are notable dilutions.

The same facts are observed around the central Kansas uplift, according to Philbrick.[18] In western Ellsworth and northern Barton counties the Ordovician waters carry 19,000–21,000 parts per million. Farther south, down the side of this great truncated uplift, in southern Barton County the concentration increases to 24,000 parts per million; in northwestern Kingman County to 68,000 parts per million; in the structurally low area of eastern Barber County to 150,000 parts per million; and in southeastern Harper County to 219,000 parts per million.

Dott and Ginter[19] show a marked concentration in the Ordovician waters down the dip from the Ozark uplift, as well as from the Arbuckle uplift. These authors state:

> There does, however, seem to be a relationship between the chemical characteristics of waters in the Ordovician section as a whole and the outcrops of Ordovician rocks in the Mid-Continent

[15] R. B. Whitehead, personal communication.

[16] R. H. Fash, personal communication.

[17] Robert H. Dott and Roy L. Ginter, "Iso-Con Map for Ordovician Waters," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 9 (September, 1930), pp. 1215–18.

[18] E. P. Philbrick, personal communication.

[19] *Op. cit.*, map, p. 1216, and p. 1217.

Also,

The most striking feature of the map is the seeming relationship between the Ordovician waters and outcrops of Ordovician rocks.

These authors conclude by stating,

The writers do not offer an explanation as to the mechanism that has brought this dilution about, but simply present the map for what it is worth.

The fact to which attention is called in the present paper, namely, that exposed porous rocks on uplifts are zones of intake of meteoric water, may explain a portion of the observed dilution.

What causes the high mineralization of waters found associated with oils?

In the recent book in which are published the results of the work done by Trask[20] and his associates on source material of petroleum occurs the following statement in a discussion of the $CaCO_3$ content of sea waters in relation to salinity.

Those people who attempt to estimate the age of the earth from the quantity of salt in the ocean assume that the salinity of the sea has been more or less constantly increasing. However, the greater age of the earth as determined by radioactivity, compared with the measurements based on sodium or chlorine in the ocean,[21] have shown that the rate of increase of salinity in the ocean has been slower than indicated by the current influx of salt into the sea. The presence of significant quantities of $CaCO_3$ in past sediments of all ages likewise suggests that the rate of increase of salinity in the ocean has been extremely slow throughout geologic time. The average surface salinity of the sea at the present time is 35.00/00. This is the dividing line between poor and rich deposition of $CaCO_3$. If this salinity is the critical salinity for past deposits, it is possible that the salt content of the ocean has not changed appreciably since Paleozoic time. This is a very radical hypothesis, but the data from recent sediments suggest that it is not impossible.

The organic forms which flourished in the seas of past geologic ages also suggest a salinity not greatly different from that of the oceans of to-day. Many geologists postulate brackish waters during the deposition of the oil-bearing sediments. Yet the waters now associated with the oils are highly mineralized. It would appear that this mineralization is due to secondary concentration.

Mills and Wells[22] regard this concentration as a secondary feature. They say,[23]

[20] Parker D. Trask, *Origin and Environment of Source Sediments of Petroleum*, (Gulf Publishing Company, Houston, Texas, 1932), p. 109.

[21] See "The Age of the Earth," edited by A. Knopf, *Natl. Research Council Bull. 80* (1931), pp. 1–9.

[22] R. Van A. Mills and Roger C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Survey Bull. 693* (1919).

[23] *Op. cit.*, p. 6.

Concentration is due in part to the leaching of the sediments by the migrating waters, but mainly to the evaporation of water by gases that are moving and expanding through natural channels.

Although clearly perceiving that the high mineralization of the oil-field waters must be a secondary feature, they subordinate all factors causing concentration to their thesis that it is evaporation in some form by moving underground gases which causes the major part of the concentration.

Perhaps a somewhat more plausible explanation of this secondary concentration is to be found in the fact that increase of pressure and temperature greatly increases the ability of water to dissolve salts. During both the primary pre-unconformity submergence and the secondary post-unconformity submergence below the underground fluid level of the reservoir rocks and their contained waters, these waters were subjected to increased pressures and temperatures,—in other words, to factors which greatly increase the leaching powers of the water. The geological evidence is considerably more definite that oil-field waters were subjected to factors which by increasing their leaching power resulted in their mineral concentration than that this concentration was due to large-scale underground evaporation by migrating gases of some kind.

Whether the increased ability of the connate water to act as a solvent due to increased temperature and pressure is quantitatively adequate to account for the observed concentrations, can not be stated here. But if it is assumed that this is true, and if there had been a notable freshening of the connate water of the reservoir rocks on an uplift undergoing deep truncation, the same factors of increased heat and pressure which would cause concentration of the water in the first place prior to erosion of the reservoir rocks would be effective when these rocks were later depressed and their contents sealed in during post-unconformity deposition. As the oil may have been subjected to potential cracking agencies on two occasions, widely separated in time, so the associated water may have undergone two periods of potential secondary concentration. The water would presumably tend to become adjusted again to a condition normal for the existing conditions of temperature and pressure. The dilution of the waters, however, which is observed near the truncated structures, indicates that they were unable to acquire again all of their original concentration.

Although the mineralized water, under the increased heat and pressure incidental to burial, was an unsaturated solution of mineral salts under these conditions, it might perhaps be a somewhat super-

saturated solution when the heat and pressure were lowered during uplift. If this were a fact, precipitation of the dissolved salts would occur, causing secondary cementation, and reducing the original porosity of the reservoir rocks. Later burial and restoration of the former heat and pressure in whole or in part might re-dissolve some of these previously precipitated salts.

For example, Philbrick[24] states that the Simpson formation exposed on the west side of the Nemaha ridge in Kansas may be divided into two areas, an eastern area flanking the ridge where very little or no fluid is encountered and a western part where an abundance of fluid is found as soon as the Simpson sands are penetrated. In regard to the sands adjacent to the Nemaha ridge he says,

> We are reasonably positive that but little fluid if any is encountered in the Wilcox sands. A few exceptions exist, but the general statement definitely applies to this area.

This greatly decreased porosity close to the pre-unconformity outcrops of the Simpson sands, as compared to areas more remote from the pre-unconformity outcrops, may be due to precipitation of salts originally present in the Ordovician waters when the heat and pressure were removed during truncation. Some of the dilution of Ordovician waters noted may also be the result of such precipitation.

Secondary cementation caused by precipitation from a solution made supersaturated by removal of heat and pressure might explain some of the streaks of tightly cemented, non-porous Woodbine sand which are so commonly encountered in the East Texas field, particularly near the east or up-dip side.

CONCLUSIONS

In the foregoing discussion no fine distinction is drawn between the time of formation of oil and the time of its accumulation. Even if the oil be not deposited as oil, there is no very apparent reason for not believing that the oil appears in the reservoir rocks by the time they undergo the deformation which permits accumulation to begin. Trask[25] suggests that the early loss of the nitrogen element in the organic portion of the sediments may indicate that a large part of the oil forms soon after deposition. The reasons for thinking the formation of the oil occurs after instead of before the unconformity are

[24] E. P. Philbrick, personal communication.

[25] Parker D. Trask, H. E. Hammar, and W. Ross Keyte, "Preliminary Study of Source Beds in Some Oil-Producing Regions," manuscript read before the Association at the Houston meeting, March 23, 1933.

based either on unproved and controversial theories regarding the origin of oil, or on the fact that a method whereby the oil could be protected during erosion of the reservoir rocks was not apparent.

The present purpose of the writer is to call attention to the position of the underground fluid level under a structural uplift during the truncation and exposure of the porous rocks. This feature is a characteristic of any uplift and assures the preservation of any fluids contained in the porous rocks, except where escape through lateral fissures is possible, as is noted. This method of potential salvation for oil which had formed and accumulated prior to truncation is so fundamental and inevitable that to challenge it is to question the operation of the law of gravitation. The mechanism by which the oil may be saved has operated beyond question.

The certain, automatic action of the protective mechanism, however, does not imply its universal effectiveness. Whether or not oil actually is saved by the operation of this process involves the time of formation of the oil and its accumulation. The problem is reduced, therefore, to the question of whether the oil formed before or after the unconformity. There is no conclusive geological evidence on this point. Comparative considerations of the geological conditions in which oil is found, where there are unconformities and where there are none, yield no definite criteria by which the date of formation of the oil can be determined.

With a process available to protect the oil during the erosional period, the most reasonable conclusion appears to be that the oil formed and accumulated during the complete geological cycle, from deposition to partial peneplanation, represented in the pre-unconformity history of the primary uplifts. Oil formed soon after burial and accumulated in reservoir rocks which later were deeply incised by erosion apparently has a reason for its present existence just as logical as if the rocks had undergone the less eventful erosional history of a section of similar age and oil potentialities without unconformities which exposed the oil-bearing strata.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 7 (JULY, 1933), PP. 843-868

GEOLOGICAL NOTES

Editor's note.—The following report "Classification and Nomenclature of Rock Units" by a committee representing the Association of American State Geologists, the United States Geological Survey, the American Association of Petroleum Geologists, and the Geological Society of America is also published in the *Bulletin* of the Geological Society of America, Volume 44 (April 30, 1933), pages 423–459. The report is republished, by permission of the Geological Society of America, for the benefit of those members of the Association to whom the *Bulletin* of the Geological Society of America is not readily available.

The original report is accompanied by a bibliography and an index which are omitted in this republication. Members interested in them are referred to the publication mentioned in the preceding paragraph.

L. C. S.

CLASSIFICATION AND NOMENCLATURE OF ROCK UNITS

BY G. H. ASHLEY, M. G. CHENEY, J. J. GALLOWAY, C. N. GOULD, C. J. HARES, B. F. HOWELL, A. I. LEVORSEN, H. D. MISER, R. C. MOORE, J. B. REESIDE, JR., W. W. RUBEY, T. W. STANTON, G. W. STOSE, AND W. H. TWENHOFEL, REPRESENTING THE ASSOCIATION OF AMERICAN STATE GEOLOGISTS, THE UNITED STATES GEOLOGICAL SURVEY, THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, AND THE GEOLOGICAL SOCIETY OF AMERICA, ON THE COMMITTEE ON STRATIGRAPHIC NOMENCLATURE (presented for publication, December 29, 1932).

CONTENTS

Introduction
  General statement
  Historical statement
Rules for classification and nomenclature of rock units
  Preamble
  Section I.—General considerations
    Article 1.—General classes of rocks
    Article 2.—Divisions of rocks
    Article 3.—Systems
    Article 4.—Formations
  Section II.—Sedimentary rock units
    Article 5.—Division of local sequences into formations
    Article 6.—Geographic limitation of formations
    Article 7.—Designation of formations
    Article 8.—Introduction of new formation names
    Article 9.—Application of rule of priority
    Article 10.—Redefinition of units
    Article 11.—Changes in rank of units
    Article 12.—Groups and series
    Article 13.—Designation of groups and series
    Article 14.—Members, lentils, tongues
    Article 15.—Designation of members, lentils, tongues
    Article 16.—Informal naming of units of less than member rank

Article 17.—Designation of subsurface units
Article 18.—Designation of surficial deposits
Section III.—Igneous rock units
Article 19.—Discrimination of units
Article 20.—Designation of units
Section IV.—Metamorphic rock units
Article 21.—Discrimination of units
Article 22.—Designation of units
Section V.—Correlation and time classification
Article 23.—Fundamental data of geologic history
Article 24.—Divisions of geologic time
Article 25.—Indication of doubtful age assignment
Article 26.—Time intervals represented by unconformities

INTRODUCTION

GENERAL STATEMENT

The numerous problems involved in the scientific classification and nomenclature of rock units have long engaged the attention of geologists. The appended partial list of papers dealing with this subject sufficiently indicates its scope and importance. Gradually, certain guiding principles have come to be recognized generally, and practices deemed good in the classification and nomenclature of rock units have become fairly well established. There is much room, however, for development of the principles and especially for the more widespread application of what seem to be the best practices in using the principles. The larger geological surveys have, necessarily, given consideration to the formulation of rules to provide for their own publications a comparative uniformity in the method of classifying and naming the rock units treated by them. But such rules have not been propounded and widely disseminated with intent to promote their use by geologists in general. Except for the work of the International Geological Congress in 1901 and earlier years, there has been no attempt by a representative group to write a body of rules or recommendations covering stratigraphic classification and nomenclature. Under these circumstances, it is, perhaps, natural that geologic workers in North America, whose number and scientific publications have increased greatly in recent years, should fail to have any reasonably uniform views as to certain principles or practices in the classification and nomenclature of rocks. It is believed that the large majority of American geologists will welcome the carefully prepared recommendations that follow, which, it is hoped, will contribute significantly to the advancement of geologic research.

HISTORICAL STATEMENT

The following rules for stratigraphic classification and nomenclature, as recommended to the geologists of the United States, are an

outgrowth of action initiated at the meeting of the Association of American State Geologists in Washington, D. C., in February, 1930. A committee of State Geologists, consisting of G. H. Ashley, C. N. Gould, and R. C. Moore, was appointed to consider the subject of variation in nomenclature of identical rock units on different sides of state boundaries and, with the invited aid of committees from the United States Geological Survey, the Geological Society of America, and the American Association of Petroleum Geologists, to consider the general subject of stratigraphic classification and nomenclature. Letters were addressed to the organizations mentioned, suggesting the desirability of a united effort to formulate principles and recommended practices that could be followed in classifying and naming rock units. As a result of this correspondence, H. D. Miser, T. W. Stanton, and G. W. Stose, of the United States Geological Survey; J. J. Galloway, B. F. Howell, and W. H. Twenhofel, of the Geological Society of America; and M. G. Cheney, C. J. Hares, and A. I. Levorsen, of the American Association of Petroleum Geologists, were designated as members of a general committee to study the subject indicated.

The first meeting of the committee, held at the office of the Illinois Geological Survey, Urbana, April 30, 1930, was attended by Ashley, Cheney, Gould, Hares, Miser, Moore, and Stanton. C. N. Gould was elected chairman and R. C. Moore, secretary. The objectives of the committee and the means of accomplishing them were considered at length. It was decided that the committee should undertake to bring to the attention of geologists the rules of stratigraphic nomenclature of the committee on geologic names of the United States Geological Survey and the facilities of that committee for the determination of previous usage of stratigraphic names. At the request of the committee, T. W. Stanton undertook to prepare a paper on the subject of stratigraphic classification and nomenclature. (This paper was subsequently published in the Bulletin of the American Association of Petroleum Geologists.) Subcommittees were designated to study and prepare reports on (1) principles of stratigraphic nomenclature, (2) interstate stratigraphic nomenclature, (3) problems of subsurface stratigraphic nomenclature, and (4) the advisability of establishing methods for advice on special problems of stratigraphic nomenclature.

The second meeting of the committee, held at the University of Toronto, Toronto, Canada, January 1, 1931, was attended by Ashley, Galloway, Gould, Howell, Miser, Moore, Stanton, Stose, and Twenhofel, of the committee, and, by invitation, J. W. Beede, E. S. Moore, and E. M. Parks. Subcommittee reports were submitted and discussed. The conclusion was reached that the chief effort of the committee

should be the compilation of recommended rules for the classification and nomenclature of rock units, and that the committee should not seek to adjudicate specific, controverted questions of nomenclature. Prolonged consideration was given to various aspects of classification and nomenclature.

Additional meetings of the committee or of several of its members were held in Washington in February, 1931, and at Tulsa, Oklahoma, in October and December, 1931. The final meeting of the general committee was held at Harvard University, Cambridge, Mass., December 29, 1932. Members present or officially represented were Ashley (Willard), Cheney, Hares, Levorsen (Moore), Howell, Moore, Stanton, Stose, Miser (Reeside), and Twenhofel. C. O. Dunbar, chairman of the National Research Council's committee on stratigraphy, was also present. The subcommittee on principles of stratigraphic nomenclature, under the chairmanship of T. W. Stanton, with H. D. Miser, R. C. Moore, M. G. Cheney, and W. H. Twenhofel, as members, formally offered, as its report, a draft of proposed rules for classification and nomenclature of rock units, essentially in the form that follows. This draft had been prepared by J. B. Reeside, Jr., and W. W. Rubey, under the supervision of H. D. Miser, and had previously been submitted to all members of the general committee for criticism, so that, in addition to suggested alterations brought up at the Cambridge meeting, some slight modifications, together with a strong general endorsement, were received from members absent from this meeting. The report of the subcommittee was unanimously adopted, and sincere thanks were extended for the arduous, painstaking labors of the subcommittee in drafting the code. Prior to the present publication, a revised, complete draft of the code has been submitted to all members of the general committee, and the recommended rules are now placed before the geologists of America.

Final action of the committee before adjournment of the Cambridge meeting was the approval of a motion that specific questions as to interpretation of the rules, that from time to time may be raised by geologists, should be referred to the committee on stratigraphy of the National Research Council, of which C. O. Dunbar, Yale University, is the present chairman. It was also agreed that the committee on stratigraphy should be asked to prepare written opinions on such questions, in order that the questions and opinions might be published at suitable intervals. This will provide a mechanism analogous to that of the International Committee on Rules of Zoölogical Nomenclature, by which questions involving principles and the interpretation of doubtful points in the rules may receive consideration by a

qualified, representative group of geologists who are special students of stratigraphy. It is well understood that no opinion of the committee, nor, indeed, any of the rules for classification and nomenclature here offered, can be mandatory upon geologists. The rules and the opinions constitute simply recommendations. The committee on stratigraphy of the National Research Council, through its chairman, has tentatively accepted the responsibility of carrying forward this continuing study of the rules and, presumably, will be the agency that may suggest modifications or amendments of the rules, if and when these seem desirable. It is perhaps unnecessary to state that the committee on stratigraphy will not undertake to offer opinions on specific questions of fact or on problems of correlation. Its proposed function is rather to clarify principles and to interpret the application of the rules. Such interpretation may involve specific questions, such as the advisability or inadvisability of employing a given stratigraphic term, where application of the rules is in doubt. Every question submitted to the committee on stratigraphy should be clearly stated in the form of an explicit query as to application of the rules and should be accompanied by a concise statement of considerations, pro and con, together with complete citations of the literature. The committee will, of course, decide whether a given question, submitted to it, is pertinent for its consideration.

RULES FOR CLASSIFICATION AND NOMENCLATURE OF ROCK UNITS

PREAMBLE

Uniform procedure is essential in dealing with the taxonomy of rock units. The need for such uniformity can be shown, merely by pointing to the duplication and multiplication of names; to the differing concepts as to the meaning of common, everyday terms, as revealed in their use; to the discordant classifications proposed by different geologists; and to other confusing features prevalent in stratigraphic literature. Without some guide toward uniformity this situation is unavoidable, for geologists deal much with matters of opinion, they are of different temperaments, have had different training for their work, and, generally, have studied unlike parts of the continent or world.

The greatest aid to uniformity would seem to be regulation by a common code of guiding principles to be followed in the classification and naming of rock units. Necessarily, such regulation would be somewhat restrictive to each individual's freedom of action. Yet, if a code of guiding principles that is generally acceptable to geologists can be

formulated, the net effect is certain to be much more beneficial to everyone concerned than it is harmful to any individual.

No code of procedure can be set up that will be entirely adequate, nor will any classification and nomenclature created under it be more than a temporary, but convenient, working arrangement. Geology is an active science: knowledge increases, and ideas change. Moreover, any attempt whatever to impose a man-made classification upon a natural system is certain to meet many difficulties: they are inherent and unavoidable, and classification of rock units is no exception to the rule.

Furthermore, no codification of rules can be completely satisfactory to all. Points of view differ, and any code that will receive general acceptance must, inevitably, represent many compromise agreements. Because of these inevitable compromises, it is, perhaps, too much to expect that any system of classification and nomenclature can be strictly logical and entirely consistent throughout for an area as large as North America, but it is reasonable to expect that a code of principles will reduce these inconsistencies to a minimum.

It is, therefore, with no delusions of perfection that this code, based on many years of accumulated experience, is offered, but with the conviction that it will be helpful in spite of its imperfections.

The plan of the code rests on two basic requirements: (1) in essentially all types of geologic investigation (whether economic, structural, physiographic, historical, or paleontologic) local rock sequences must be divided into separate rock units; (2) for purposes of cartographic representation, intelligible description, and historical interpretation, these local rock units need to be correlated with other and better known units in other areas.

SECTION I.—GENERAL CONSIDERATIONS

Article 1.—Three general classes of rocks are recognized, as follows:

(1) *Sedimentary*, including all rocks formed by aqueous, organic, glacial, and eolian agencies.

(2) *Igneous*, including all rocks that have been solidified from a molten condition, both volcanic and plutonic.

(3) *Metamorphic*, including altered rocks of either sedimentary or igneous origin in which the acquired characteristics are more prominent than the original characteristics.

Remarks.—Deposits whose classification is debated or which do not fall clearly within one of the above-enumerated classes may also be recognized such as *talus*, *landslides*, *pyroclastic rocks*, *veins*, and *residual ores*.

Article 2.—The following divisions or units of rocks are recognized:

(1) *System*, a standard, world-wide division; contains the rocks

formed during the fundamental chronologic unit, a period. (See Article 24.) Example, *Devonian system.*

(2) *Series*, a major subdivision of a system; contains the rocks formed during a major subdivision (an epoch, in its widest sense) of a period. (See Article 24.) In part, the series, as actually used in the United States, is nearly an equivalent of the comparable European subdivision—for example, *Lower Devonian series, Eocene series;* in part, the series is a convenient unit, of size approaching that of the comparable European subdivision but not necessarily equivalent to it. In this second usage, a provincial name may be applied—for example, *Comanche series, Shasta series, Cincinnatian series.*

(3) *Group*, a local or provincial subdivision of a system, based on lithologic features. It is usually less than a standard series and contains two or more formations. (See Article 12.) Example, *Mesaverde group.*

(4) *Formation*, the fundamental unit in the local classification of the rocks. (See Sections 2, 3, and 4.)

(5) *Member*, *lentil*, and *tongue*, subdivisions of a formation. (See Article 14.)

(6) *Bed*, *stratum*, and *layer*, the smallest units recognized in classification. (See Article 16.)

(7) *Zone*, a subordinate unit containing the rocks deposited during the time of existence of a particular faunal or floral assemblage. It may be of the magnitude of a bed, a member, a formation, or even a group. (See Article 16.)

Remarks.—(*a*) No term for a rock unit coördinate with *era* (see Article 24) is in common use, though *group* was, at first, chosen for this purpose by the International Geological Congress, and later abandoned. The term *stage* was adopted by the Congress for rock units that are subordinate to series, but in America this term has almost no usage other than as a time term for major subdivisions of the Pleistocene epoch—for example, *Wisconsin glacial stage, Yarmouth interglacial stage.*

(*b*) The term *horizon* is not included in the above list, for it denotes merely position. A horizon has no thickness, being merely a stratigraphic level, or plane.

(*c*) In the designation of series, where *Lower*, *Middle*, and *Upper* are used in conjunction with the name of a system, the initial letter shall be capitalized, All other uses of *lower*, *middle*, and *upper* shall be written with a small letter. None of the designations of units—*systems*, *series*, *group*, *formation*, etc.—shall be written with a capital initial.

(*d*) Systems, series, groups, and formations are customarily given formal names; members, lentils, and tongues are commonly, though not necessarily, named; beds, strata, and layers are rarely given formal names, though in the economic applications of geology informal names for such units are not uncommonly used. (See Article 16.) Zones are customarily given a paleontologic name (generic or specific). (See Article 16.)

(*e*) Systems, series (in part), and zones imply a time element as an essential feature in their discrimination. Series (in part), groups, formations, members, lentils, tongues, beds, strata, and layers are based on lithology and may not correspond to specific, widespread time divisions; therefore, they differ essentially from the other three.

(*f*) A special, limited use of series, sanctioned by custom, is that in which it is applied to igneous rocks. (See Article 20, paragraph *g*.)

Article 3.—For general classification, the formations shall be referred to systems, which are defined as the assemblages of rocks formed during the fundamental time units, the periods. (See Articles 23 and 24.)

Remarks.—In general, the definition and limits of the systems and the correlation of the local representatives of the standard systems are determined primarily by paleontology and secondarily by structural and stratigraphic relations. The exceptions are the Quaternary system and the systems recognized in the pre-Cambrian. The criteria for definition of the Quaternary, for determination of its beginning, and for correlation within it are based primarily upon the concept of widespread climatic changes contemporaneous with the several glaciations of the Pleistocene epoch. The characters by which the pre-Cambrian systems are discriminated are lithologic and structural.

Article 4.—The formation is the fundamental unit in the local classification of rocks. The larger units, groups and series, may be regarded as assemblages of formations and the smaller units as subdivisions of formations.

Remarks.—The word *formation* is to be used as the designation of a specific unit, not as the general term representing the results of a mode of formation, though this usage has had some currency, as, fluvial formation, lacustrine formation, etc. The words *rocks* and *deposits* are often used in such phrases and seem to serve satisfactorily.

SECTION II.—SEDIMENTARY ROCK UNITS

Article 5.—The discrimination of sedimentary formations is based on the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic characters change or where there are significant breaks in the continuity of sedimentation or other evidences of important geologic events. As thus conceived, the formation is a genetic unit, which may represent a long or short period of time, which may be composed of materials from different sources, and which may include minor breaks in the sequence. Exceptionally, as a matter of expediency, a formation may include major breaks in the sequence.

Remarks.—(*a*) The selection of formations shall be such that they will best meet the practical and scientific needs of the users of geologic maps. It is, generally, impossible to represent on a map the limits of each lithologic change, and the geologist must select for the limitation of formations such horizons of change as will best express the geologic development and structure of the region and will give to the formations the greatest practicable unity of constitution. In determining this unity of constitution, all available lines of evidence, including lithologic constitution, fossil content, structural relations, and unconformities, shall be considered.

(*b*) In general, lithologic constitution is accepted as the controlling basis of subdivision, partly because of its usefulness and immediate availability in mapping, and partly because of its genetic and economic significance. Each formation shall contain between its upper and lower limits, either (*a*) rocks of one dominant lithologic type or facies, or (*b*) a repeated interlamination of rocks of two or more lithologic types or facies, as, for example, an alternation of shale and sandstone. There may, in some areas, be justification for a formation marked by extreme heterogeneity of constitution, but that, in itself, may constitute a form of unity.

(*c*) Where the passage vertically through a sequence of beds from one type of

rock to another appears to be completely gradational, it may be necessary to separate two contiguous formations by an arbitrary line. Or paleontologic evidence may indicate that a sequence of closely similar lithologic character does not represent essentially continuous deposition, but includes an important, but obscure, unconformity, and that a separation into two formations is desirable. Under such circumstances, it may be necessary to depend, almost entirely, on the contained fossils, in separating the formations. Nevertheless, a unit distinguishable from the enclosing rocks only by its fossils shall not, in general, constitute a formation, but is properly classified as a paleontologic zone.

Information in hand concerning a sequence of beds may be inconclusive as to the advisability of division—for example, as to whether a sequence of similar beds, containing upper Mississippian fossils in the lowermost part and lower Pennsylvanian fossils in the uppermost part, is continuous or is broken by a considerable hiatus. Or, in practical work, it may not be useful to make a division, even though evidence is in hand—for example, where a break is known within a sequence of beds whose lithology is virtually identical above and below the break, and which has never been separated into units by any mapping or other continuous general study. Such a formation, as thus recognized, may include a major break, though it is ordinarily expected that later work will make division of the unit feasible.

(*d*) Although the practicability of mapping is usually an essential feature, and, indeed, may be the chief factor, in the discrimination of a formation, it may, under exceptional conditions, be waived. It may be impracticable to show separately, even on a fairly detailed map, thin rock units which, by various other criteria, are valid formations.

(*e*) The thickness of a formation is not a determining feature in its discrimination. A formation only 10 feet thick may be adjacent to another 5,000 feet thick.

Article 6.—Inasmuch as a formation is conceived as a genetic unit formed under essentially uniform conditions or under an alternation of conditions, and inasmuch as such environmental conditions were local as well as temporary, it is to be assumed that each formation is limited in horizontal extent. The formation should be discriminated and should be called by the same name as far as it can be traced and identified by means of its lithologic character particularly, but also by its stratigraphic association and its contained fossils. It is not necessary that a formation be of precisely the same age at different localities, and there may be marked difference in age from place to place.

Remarks.—(*a*) It is customary, particularly where exposures are not continuous, to give different names to deposits of different lithologic constitution, even though they may be essentially contemporaneous—for example, a unit of chalk in one area and a unit of shale in another (as *Smoky Hill chalk, Kansas*, and *Apishapa shale, Colorado*), or of limestone in one area and other rocks in another area (as *Twin Creek limestone, Wyoming*, and *Carmel formation and Entrada sandstone, Utah*). There have been some exceptions to this practice, however, where a formation changes within relatively narrow lithologic limits and very gradually from one lithologic facies to another and yet retains its original stratigraphic association and carries the same fauna—for example, *Ottosee limestone* and *Ottosee shale*, *Warsaw limestone* and *Warsaw shale*, *Athens limestone* and *Athens shale*, in each of which the shale is calcareous. It is desirable, where one name is applied to different lithologic facies, that there be approximate continuity of exposures, and it is not good practice to extend a name across considerable gaps in exposure to other units of different lithologic constitution—for example, to carry the name *Onondaga* from its original limestone facies in New York to a green shale in Virginia.

(*b*) On the principle that similar lithologic constitution shall be the essential character in the extension of a name away from its type area, and that difference in age from place to place is permissible, the same name may be applied for cartographic purposes to a lithologic unit which, elsewhere than at the type locality, includes either a greater or a smaller stratigraphic interval. It is conceivable that exceptionally the interval

covered by such a name may, at some localities, have no part in common with that included in the unit at its type locality. However, if appropriate lithologic units can be discriminated, or if convenient geographic divisions can be made, it is well to avoid such extremes. Examples of formations which are believed to include different intervals from place to place are the Saint Peter sandstone, Dakota sandstone, Trinity sand, Catskill formation, Mancos shale, and Lewis shale.

(*c*) Where, in a limited region, the named lithologic units are relatively numerous, and there are, in addition, many lateral changes in lithologic constitution within relatively short distances, the lateral extension of names presents particular difficulties. The nomenclature, if carried out on the usual basis, becomes so complicated as to lose its usefulness. For example, the Pennsylvanian rocks of Kansas and Nebraska have been divided into many thin units. At places, the components of a series of alternating limestone and shale units pass into an indivisible shale body. The problem is thus presented of what name, or names, to apply to the shale body, whose recognizable boundaries change abruptly as each limestone bed disappears from the sequence. A specific example is the sequence that includes, in ascending order, the Lane shale, Wyandotte limestone, Bonner Springs shale, Plattsburg limestone, and Vilas shale. Laterally, the Wyandotte limestone passes out and the Lane and Bonner Springs shales form one body; then the Plattsburg limestone passes out, and the Vilas shale is added to the other shale units to form one shale body. Farther on, the Plattsburg limestone appears again, but the limestone beneath the Lane shale passes out, and the Lane, Bonner Springs, and an older shale (Chanute) form one unit. If to each of these distinct shale intervals is given an individual name, there results within a relatively small area, a large number of names representing units that are continuous laterally and indistinguishable by lithologic features. It is simpler, and it is permissible under such special conditions, to extend to the combined units the names of the lowermost and uppermost units of the complete sequence that enter into the combined units, separating the names by a hyphen. Thus, the combined units cited above would be called *the Lane-Bonner Springs shale*, *the Lane-Vilas shale*, and *the Chanute-Bonner Springs shale*, respectively.

(*d*) Such a phrase as *shale of Warsaw age* shall not be construed as specific extension of the geographic part of the name into a region where it has not previously been applied.

Article 7.—All sedimentary formations shall receive distinctive designations. In general, the names should be binomial, the first part being geographic, and the other, ordinarily, lithologic (as, *Dakota sandstone*), though if the formation consists of beds differing greatly in constitution, so that no single lithologic term is appropriate, the word "formation" may be substituted (as, *Monmouth formation*).

Remarks.—(*a*) The only exception to the naming of sedimentary formations is that, in some areas, superficial units, such as alluvium and terrace deposits, are mapped but are only in part named.

(*b*) The geographic term should be the name of a river, town, or other natural or artificial feature at or near which the formation is typically developed. A specific locality should be cited which shows a typical development of the unit, and it need not be the exact locality from which the geographic name is taken, though it should not be far removed.

A formation should not be named from the source of its materials—for example, *Keewatin drift*, for materials derived from the Keewatin center.

(*c*) Names taken from natural features are generally preferable, because less changeable, to those of towns or political divisions. Names derived from evanescent sources such as the ownership of farms or ranches, are particularly objectionable but such names are permissible if no others are available.

(*d*) Geographic names consisting of more than one word should be avoided. Descriptive terms, such as *mountain*, *river*, *creek*, *gulch*, *fort*, and *city*, shall, in general, be excluded from new names, and it is desirable, where practicable, to drop such terms from old names, but it may be necessary in a few cases of scarcity of names to retain the terms for distinction from a prior name.

(*e*) The rulings of the appropriate national board, such as the United States Geo-

graphic Board, should govern the spelling of geologic names derived from geographic names.

(*f*) Precise duplication of geographic names of sedimentary units shall not be allowed, except as a most urgent necessity because of the scarcity of available names or other conditions, and then only if geographic and stratigraphic separation is such as to preclude any possible chance of confusion. This rule shall apply with less rigidity to duplication of the name of a sedimentary unit for an igneous unit, but such duplication is permissible only for widely separated localities. (See Article 9). Known synonyms should be eliminated as far as possible, though experience has shown that such elimination is sometimes prevented or long delayed by local or political or personal considerations.

(*g*) When it seems useful to refer to an obsolete or abandoned formal name, the status of the name should be made clear by some such term as *abandoned* or *obsolete;* or, this may be indicated by using the name preceded by a dagger, as †*Lafayette gravel*, †*La Plata sandstone of Cross*. A name, once current and then abandoned, is no longer available for any use other than that of restoring the original usage. (See Article 9.)

Some organizations maintain an official list of adopted names. It sometimes becomes necessary in publications of the organization to use a name not yet adopted or sponsored by the organization. Or, an individual author may wish to use a name, already in the literature, that he does not care to sponsor. Such a name may be used, in a quotational sense, with an added phrase: as, *the Jonesville formation of Smith*.

(*h*) A name that suggests some well-known locality, region, or political division shall not, in general, be applied to a formation or other unit typically developed in another less well-known locality of the same name. It would not, for example, be advisable to use the name *Chicago formation* for a unit in California.

(*i*) Names based only on petrographic or paleontologic features are not to be used as formal names in place of geographic names—for example, *Corniferous, Magnesian, Crinoidal, Saccharoidal*. Where such names have been applied in the past but have been replaced by geographic names, they shall, if used, be placed in parentheses and quotation marks, as *Ames* ("*Crinoidal*") *limestone*.

(*j*) Generally accepted petrographic or genetic terms shall be used for the lithologic part of a formation name; as, *limestone, sandstone, shale, tuff, lake beds, fanglomerate, mud flow, channel sandstone, redbeds*. Combined terms, such as *sand and clay*, shall not be used for the lithologic part of the names of sedimentary units of formation rank, nor shall an adjective be used between the geographic term and the lithologic term; as, *Chattanooga black shale* and *Biwabik iron-bearing formation*. *Waterlime* is not recognized as a lithologic term and is to be replaced by *limestone*.

(*k*) Prior usage shall not prevent greater exactness in lithologic designation resulting from further work on a formation, as, for example, to replace *limestone* by *dolomite*, or *shale* by *mudstone*, but unfamiliar or complicated petrographic names should not be thus introduced.

(*l*) Sedimentary and volcanic rocks that are interbedded and inseparable may be assembled into a formation under one name.

(*m*) If applied to indefinite or local subdivisions of stratigraphic units, the adjectives *lower, middle,* and *upper* shall not be capitalized, except where the term is quoted and the quotation indicated—for example, *Lower Atlantic Miocene of Heilprin*.

(*n*) Neither the lithologic part of a formation name nor the word *formation* shall be capitalized.

(*o*) Where the omission of descriptive terms is compatible with clearness, or where frequent repetition would make a cumbersome style, the geographic name may be used alone; as, *the Burlington*, for the Burlington limestone.

(*p*) It is permissible to use such expressions as *the formation* or *this formation* in reference to a formation, even though it is formally designated *sandstone, limestone,* or some other lithologic term.

(*q*) Geologic provinces do not coincide with political units. Nevertheless, formations are, in general, limited in extent, and for this reason it is generally inadvisable to extend into a country the use, for formations and members, of geographic names derived from localities in another country. It may, however, prove advisable to adopt the names of well-established units that cross international boundaries. It is desirable to avoid conflict of well-known names between different countries. (See paragraph *f*.)

(*r*) Names of soils are not regarded as geologic names and do not conflict with stratigraphic names.

(*s*) Names applied to morainic deposits are in a special class (see Article 18) and

do not conflict with stratigraphic names, even in the same region, though usage in these matters should be considered.

(*l*) The name of the formation in which fossils of a described fauna or flora are found shall be given in the description of each species, even if the title of the paper would seem to imply that all the fossils came from the same formation.

Article 8.—Each new formation that receives a formal name must be explicitly defined at the time of its proposal, though this rule shall not be construed as invalidating well-established names. The definition must cite the geographic feature from which the name is taken. It should cite, also, a specific locality at which the unit is typically developed, and should include a statement of the important facts that led to the discrimination of the formation and a statement of the characteristics by which it may be identified, whether by geologist or by layman.

Remarks.—(*a*) It is requisite that a proposal of a new unit be duly published through one of the usual agencies of scientific publication before it shall have any validity.

It is difficult to define specifically what is meant by the phrase "usual agencies of scientific publication." Size of edition is not, in itself, a determining factor. Form of publication (type printing, mimeographing, lithography) is not a determing factor—that is, for example, mimeographed matter may constitute valid publication. Availability to the scientific public is the chief determining factor. A publication must be generally available, either on request or by purchase. Publication in a well-known, regularly issued, numbered series naturally meets this requirement. Many independent publications also meet it, though it is needful for independent publications that some form of notice of publication appear in scientific journals. Such ephemeral issues as the press notices of the United States Geological Survey are not to be considered agencies of publication under this rule. These press notices, for example, are not issued in a series and are not recognized in the organization's own list of publications. Proposals of names in informal or restricted mediums, such as letters, company reports unavailable to the public, or unpublished addresses, shall have no status in stratigraphic literature. Publication in newspapers and commercial or trade journals is not valid publication.

It is requisite that there be definite intent on the part of the author to establish a new name. Mere casual mention, such as "the formation at Jonesville schoolhouse," shall not establish a new name; nor shall bare use without definition, as in a table or a columnar section, establish a new name.

(*b*) Among the details given in the description of a sedimentary formation should be included a summary description of the lithology, a detailed section at, or near the geographic feature from which the unit is named (see Article 7, *b*), a statement of the variations in thickness, a statement of the distribution of the formation, a list of the contained fossils or, at least, of the significant fossils, a description of the upper and lower contacts, a statement of the physiographic expression of the formation, and an interpretation of the correlation and age.

Article 9.—In the application of names to formations, the rule of priority, that the first geographic name applied to any unit and duly published shall be accepted, shall generally be observed; but a name that has become well established in use shall not be displaced, merely on account of priority, by a term not well known or only slightly used. A name that has previously been applied to any unit shall, in general, not be later applied to another unit.

Remarks.—Priority shall be defined as priority of date of publication. (See Article 8.) Other things being equal, page precedence should decide, as in other sets of rules governing scientific nomenclature.

The term "well established," as used in this article, is difficult to define specifically. The acceptance of a name by several authors is generally taken as establishing it.

Article 10.—The redefinition of a unit to change its content of rocks, where such change is demanded by later work, does not necessarily render renaming advisable.

Remarks.—The immediate circumstances must determine whether, for example, the Pinkney formation of an older classification shall become, in later elaboration, the Pinkney group, containing several formations, or shall be divided into a restricted Pinkney formation and one or more other formations; or whether the shifting of one or both boundaries will make the unit more natural and reasonable.

Article 11.—The rank of a unit, where circumstances dictate, may be changed without changing its name or its content of rocks. It is thus possible for a member to become a formation, or a formation to become a group; or the process may be reversed.

Remarks.—(*a*) An assemblage of rocks may change its thickness or character notably from one region to another, to such an extent that, for cartographic purposes, (1) a member may become a formation; (2) a formation, with or without named members, may become a group; and (3) a formation may become a member. For example, the Morrow is recognized as a formation in Oklahoma and as a group in Arkansas; the Osgood formation, Laurel dolomite, and Waldron shale of Indiana are classed as members of the Wayne formation in a portion of Tennessee; the Virgelle sandstone is a formation in western Montana and a member of the Eagle sandstone in central Montana.

(*b*) In the inevitable subdivision of rocks, as work progresses in a given region, it often becomes desirable to change the rank of a unit, without changing its content of rocks—for example, the Mesaverde formation of early work on the Mesa Verde, Colorado, became, in later work, the Mesaverde group, containing three formations.

(*c*) In changing the rank of a unit, or in redefining the unit, it shall not be permissible to apply the same name to the unit and to a part of it—for example, the Astoria group shall not contain an Astoria sandstone, nor the Washington formation a Washington sandstone member.

Article 12.—Formations may be assembled to constitute groups and series. Ordinarily, the series is divided into groups, but groups may be constituted without the recognition of series.

Remarks.—(*a*) These minor aggregates should be so formed as to express the natural relations of the formations of the particular region or province, rather than to conform to the divisions recognized elsewhere, though they may prove to have a wider distribution.

(*b*) Sedimentary and volcanic rocks may be assembled into a group under one name, where such association is useful.

Article 13.—Groups shall receive geographic names, which shall be subject to the same restrictions and regulations as apply to formation names. Provincial names applied to series shall also be subject to these restrictions and regulations. (See Articles 7, 9, 10, and 11.)

Remarks.—(*a*) Where accepted units are, for any reason, not separated in the field, or where, because of the technical difficulties of representation on maps, they are not shown separately, it may become necessary to consider together formations or groups that are not ordinarily combined into a group or series. For these informal aggregates, the names of the constituent formations or groups should be stated—for example, *Dakota and Morrison formations; Washita and Fredericksburg groups; Burlington limestone, Sedalia limestone included at the base; Plattin limestone, Decorah formation included*

at the top. Where the formations have not been separated in the field, it is common to add the word *undifferentiated*.

In map explanations and elsewhere, it is customary to name the units in order of age, the youngest first; but where one unit is more conspicuous than the others, it may be desirable to depart from this order.

Where more than two units are combined, it is, ordinarily, better to list the units, though the names of the youngest and oldest units may be used, united by the word *to*.

(*b*) In the naming of groups, a lithologic term is not necessary, but in the case of a group composed of formations of one dominant lithologic type, the appropriate lithologic term may be combined with the group name; as *Ohio shale group*, *Stones River limestone group*.

(*c*) The term *group* may be applied in reconnaissance work, particularly in Alaska, to assemblages of rocks that have some stratigraphic unity but that have not yet been subdivided. It is to be expected that in later work, such groups will be divded into named formations.

Article 14.—When, for scientific or economic reasons, it is desirable to map, or simply to recognize, one or more specially developed parts of a varied formation, such a part should be called (1) a *member*, if it has considerable geographic extent; (2) a *lentil*, if it has slight geographic extent; (3) a *tongue*, if it is known that in one direction it wedges out, laterally, between sediments of a different lithologic constitution, and in the other direction, thickens and becomes part of a larger body of like sediments.

Remarks.—The proper designation of these lesser units rests largely on the accidents of exposure. In all probability, the form they happen to present is a result of the direction in which erosion has cut into them. A body revealed as a lentil might have been a narrow tongue, or a wide tongue might have been a member if cut in another direction.

Article 15.—Members and coördinate subdivisions shall be named in the same manner as formations (see Articles 7, 9, 10, and 11), except that it is usually not advisable to name all members, and that, in the formal name, it is necessary to add the word *member*, *lentil*, or *tongue* to the lithologic designation. Example, *Wedington sandstone member of the Fayetteville shale*.

Remarks.—(*a*) Where the distinction of a unit of member rank depends on some property not expressed by the lithologic noun alone, the insertion of an adjective is permissible—for example, *Roundtop red sandstone member;* and the adjective may even be substituted for the lithologic noun where this is the same as that of the formation—for example, *Mowry siliceous member of the Graneros shale*.

(*b*) It is not necessary that members, named or unnamed, be mapped. If all of a series of units are extensive and are named and mapped on a scale of 1 mile or more to the inch, it is generally desirable that they be considered formations rather than members.

(*c*) If no one lithologic or descriptive term is appropriate, a member may be designated by a geographic name, without a lithologic term—for example, *Morales member of the Santa Margarita formation*.

(*d*) Where members of formations are continuous for long distances, as in the Pennsylvanian and Permian rocks of Kansas and Nebraska, it may be desirable to name all members of a formation.

(*e*) The use of the words, member, lentil, and tongue, as portions of the formal geologic name is advisable in:

(1) Columnar and stratigraphic sections—for example, *Parkhead sandstone member*.

(2) Tables and lists of contents.
(3) Headings.
(4) Formal statements and discussions of stratigraphy.
(5) Map explanations.
(6) Formal, detailed descriptions of fossils.

These terms may not be necessary:

(1) Where the geologic name is given in parentheses—for example, *sandstone 16 feet (Parkhead)*.
(2) Where omission of all descriptive terms is compatible with clearness.
(3) In referring to beds of only economic importance.
(4) Where frequent repetition in small compass makes cumbersome English.

Article 16.—Units of less than member rank—for example, individual beds—shall not, in general, receive formal names. Informal or colloquial names may be applied, if expedient, such as the names in common use, in the economic applications of geology, for coal beds, oil sands, or quarry layers. These names, as such, shall not have a part in formal stratigraphic nomenclature. However, such units may be taken into the formal nomenclature by the assignment of a geographic name and designation as a member or formation, and when so adopted, the member or formation name shall be used first and the informal name added in parentheses.

Remarks.—(*a*) Trade names or other informal names shall be taken into consideration in the selection of a formal name for the geologic units to which they are applied; but the rule of priority need not be rigidly applied in the adoption of such a name, if it is found that various names have been applied in different areas to the same geologic unit.

(*b*) Although it is generally inadvisable to apply formal geographic names to units of less than member rank, it is conceivable that such usage may sometimes serve a useful purpose—for example, in describing a very thin but widespread bed such as the unit commonly called the *Hounsfield metabentonite*.

(*c*) The application of identical geographic names to several minor units in one vertical sequence is always to be considered informal nomenclature—for example, the *lower Mount Savage coal*, *Mount Savage fireclay*, *upper Mount Savage coal*, *Mount Savage rider coal*, and *Mount Savage sandstone*. So, also, is the application of identical geographic names to the several lithologic units constituting a cycle of sedimentation, such as is described for certain Carboniferous rocks. This sort of informal duplication of geographic names for units of differing constitution in a vertical sequence should be distinguished from the formal duplication permitted for lateral change in lithologic constitution within the same stratigraphic interval. (See Article 6.)

(*d*) A minor subdivision, based primarily on fossil content, may be designated a *zone* and named after a characteristic fossil, as *Hypothyris cuboides zone*, or a characteristic genus, as *Dufrenoya zone*. Such informal terms as *cephalopod zone* are permissible, but they shall not have a part in formal stratigraphic nomenclature. An informal descriptive term, such as *Lecanospira-bearing limestone*, is permissible, and so, also, are such quoted terms as "*Lecanospira* limestone" or "*Lecanospira* beds," where such terms are already in the literature and it is desirable to show their relations. (See Article 2.)

Article 17.—Subsurface units shall be given formal names only where names are necessary for adequate presentation of the geologic history of the region.

Remarks.—(*a*) Subsurface units, recognized and named from well logs with the assistance of data derived from cuttings or cores, have a special status by virtue of the fact that the type data are usually indirect and the type locality, at best, is accessible only during the original work. Even when all materials are preserved by the original

author and can be inspected by later students, it will never be possible to repeat the original work in the same manner as when dealing with exposed formations. It is desirable, therefore, to keep the number of formal names applied only to subsurface units as small as possible.

(*b*) Names applied to subsurface units shall be governed by the same restrictions and regulations as prevail for exposed units. (See Articles 7, 9, 10, and 11.)

(*c*) When it becomes possible to correlate a named subsurface unit with a named surface unit, the name of the surface unit is to be applied, even though the subsurface name has priority.

(*d*) In proposing a new name for a subsurface unit, it is desirable to describe, for the type section, the following features:

(1) Location of the type-locality well, as accurately as possible; name of operating company or individual; date of drilling; results and present status of the well; elevation of surface at the well and depth to top and bottom of the new unit.
(2) Lithology, upper and lower contacts, and drilling characteristics (hard, soft, sticky, etc.) of the new unit.
(3) Fauna and flora.
(4) Nature of underlying and overlying units.
(5) Correlation and position in the general stratigraphic scale.
(6) Present location of the cuttings or samples.
(7) Present location of the fossils.
(8) Log of the well.

The cuttings and the fossils, accompanied by copies of the log, should be placed in some official, permanent depository.

Article 18.—In the naming of surficial deposits that are chiefly of Tertiary and Quaternary age, geographic names may be used; but, in general, formal names shall not be applied to deposits of merely local extent. Names for general or widely recognized units, such as the Wisconsin till, shall be subject to the restrictions and regulations that apply to other stratigraphic names, but informal names for distinctly local deposits and physiographic names for land forms shall not be so subject. (See, also, Articles 2, paragraph *a;* 7, paragraph *j;* and 26.)

Remarks.—(*a*) In the past, constructional land forms—that is, land forms built up of superficial deposits—have been somewhat confused, in the nomenclature of parts of the Tertiary and Quaternary, with the deposits themselves and with the time intervals represented by their formation. Constructional land forms and destructional land forms record the geologic events of certain time intervals; and, in many places, such land forms occurring in series, afford the best record of the local sequence of events and the best basis for regional correlations. Yet, in spite of the fact that they have this time significance, constructional land forms, as such, are no more properly considered stratigraphic units than are destructional land forms. Hence, the geographic names applied to constructional land forms, apart from deposits, do not fall within the field of stratigraphic nomenclature, although the names that are applied specifically to their constituent deposits do.

(*b*) The term *moraine* has, in practice, been applied both to the land forms and to the constituent glacial deposits. Where the term has been applied to deposits in conjunction with a geographic name, the terminology is purely stratigraphic; but where the terms *moraine* and *morainic system* have been applied to the morainic ridges, as such, in conjunction with a geographic name, the units are land forms (physiographic units), not stratigraphic units. Thus, the Bemis moraine, a single ridge; the Altamont morainic system, consisting of a number of associated ridges; and the Gary moraines, a group varying locally from one to five ridges, are all physiographic units, and are all composed of late Wisconsin drift, a stratigraphic unit. (See Article 7, paragraphs *b* and *s*).

Among other land forms which are built up of surficial deposits and to which this principle may apply may be mentioned drumlins, eskers, beaches marking shore lines of ancient lakes, deltas, stream fans, alluvial slopes (such as those in the arid West that

are characteristically composed of fanglomerate), alluvial plains, terrace plains, terraces representing remnants of alluvial plains, dunes, volcanoes, cinder cones, and other constructional forms made of extrusive volcanic materials.

(*c*) The geographic part of a formation name applied to a surficial deposit may, where it seems desirable to the author, be applied to the land surface formed by that formation, provided that the top of the deposit is essentially the original constructional surface; and it may also be applied to any contiguous surface, whether constructional or destructional, that is of the same age. A formation name should not be applied to the surface or the unconformity beneath a formation, unless the deposits are so thin and scattered that their upper and lower surfaces can not, with convenience, be mapped separately. It is particularly undesirable that a name be duplicated for a land surface and for a rock unit of totally different age in the same general region—for example, *Jonesville erosion surface* and *Jonesville sandstone*. (See Article 26.)

SECTION III.—IGNEOUS ROCK UNITS

Article 19.—The discrimination of formations, especially as cartographic units, among the igneous rocks of any region is desirable in order to represent three kinds of facts:

(1) The mode of occurrence; as, lava flows, stocks, dikes, laccoliths, etc.

(2) The mineral and textural characters, which are, in part, controlled by the chemical composition of the magma, but, in part, influenced by local conditions of consolidation.

(3) The chemical composition, which is, to some extent, expressed in the nomenclature of the rocks.

Remarks.—(*a*) The constant or varying chemical character of the magmas erupted at different times from one vent, and the similarity or contrast of those erupted in widely distinct periods, or in different areas, are important features in geologic history, and must be considered in classification. Though all the petrographic divisions founded upon the various characters of igneous rocks can not usually be represented on a map, it is permissible and desirable to discriminate all units whose characters render them locally notable or of economic importance. Inasmuch as rules can not be laid down to cover the details of such matters, the geologist is expected to exercise his judgement as to what is desirable in each case.

(*b*) Facies of a single geologic body of igneous rock may be discriminated, cartographically, without showing a definite contact between them, if they are truly transitional. Composite igneous bodies may, exceptionally, be mapped as units, but this should not be regarded as standard practice if the map scale permits their distinction.

Article 20.—The name by which an igneous formation is designated may consist of (1) the petrographic term alone, or (2) a geographic term and the petrographic term, if a geographic name seems useful.

Remarks.—(*a*) The petrographic term for cartographic use should be one that is comparatively well known—for example, *granite* or *basalt*—though it may, exceptionally, indicate a mode of occurrence, as *lava*, *tuff*, *sill*, or *dike*. The more technical rock designations and classifications may be given in the descriptions in the text of the accompanying report, though, where no well-known group term applies, the simplest technical name possible should be used. A modifying adjective or a hyphenated term may be used where necessary; as, *porphyritic*, *rhyolite-dacite*, *soda rhyolite*, *breccia-agglomerate*.

(*b*) If an igneous formation consists of members so diverse in character that no single petrographic term can be selected which indicates its dominant type the word *formation* shall, ordinarily, be used in place of the petrographic term.

(*c*) If a large mass is composed of diverse rocks of any class or classes and is characterized by highly complicated structure, the word *complex* may be used instead of a petrographic term.

(*d*) The local importance of igneous masses may render the use of a geographic term, in connection with the petrographic name, highly advantageous. By this means, not only may different masses of one petrographic type be designated, but petrographic differences may be emphasized without recourse to technical names—for example, *Montezuma quartz monzonite, Pikes Peak granite.*

(*e*) Geographic names used for igneous formations shall be subject to the same restrictions and regulations as apply to names used for sedimentary formations, except that a geographic name applied to an igneous mass of small lateral extent need not be as rigidly subject to the rules of priority and duplication as names for sedimentary formations, though these rules shall be followed whenever possible (see Article 7, paragraph *c*, and Article 9). For small masses, it is usually sufficient to use informal designations, such as *the basalt of Table Mountain, quartz monzonite in Buckskin Gulch, granite at the Bluebird mine.*

(*f*) If a formal name is given to an aggregate of two or more igneous formations, the first part of the name shall be a geographic term and the second part the word *group*, or a term, such as *granite group*, indicative of the character of the group. A group of igneous formations may comprise units related as a superposed sequence, or it may comprise units related in some other way—for example, a number of bodies of similar granite may receive collectively a group name.

(*g*) The rocks resulting from a succession of extensive eruptions may be called a *series*. Such a name should always include, between the geographic term and the word *series*, an adjective term like *basalt*, *volcanic*, or *intrusive*, indicative of the character of the series and marking the usage as different from that for standard series, in which a lithologic term is not used.

(*h*) Sedimentary and volcanic rocks that are interbedded and cartographically inseparable may be assembled into a formation. Alternations of sedimentary and volcanic formations may be assembled into a group.

(*i*) Some assemblages of volcanic rocks consist dominantly of lava and pyroclastic rocks of different kinds that can not conveniently be separated for cartographic purposes, except perhaps locally, either because of rapid lateral variation or because of close similarities in appearance, resulting from metamorphism or other causes. To such an assemblage, the word *volcanics* may be applied—for example, *Casto volcanics.*

SECTION IV.—METAMORPHIC ROCK UNITS

Article 21.—The discrimination of formations, particularly as cartographic units, among metamorphic rocks should be based, primarily, on their petrographic features. Within the limits so established, however, units should be chosen to show, as far as possible, (1) the mutual relations of the formations and their relations to other geologic bodies; (2) their intrinsic structural features, such as schistosity, cleavage, and mylonitization, which may be a significant index to their origin and history.

Remarks.—(*a*) Inasmuch as metamorphic rocks have been formed by various processes from many sorts of sedimentary and igneous rocks, and as the changes effected may have proceeded to various degrees of completeness, the resulting products are exceedingly varied. The discrimination of formations in metamorphic rocks is, therefore, too complex a problem to permit the laying down of rules to cover details. As with igneous rocks, it is permissible and desirable to discriminate all units whose character renders them locally notable, or which are of economic importance. The geologist must exercise his best judgment in each case.

(*b*) For cartographic purposes, masses of metamorphic rocks of approximately uniform character that are large enough for representation should be discriminated.

(*c*) If an aggregate of metamorphic rocks, such as schists and gneisses, changes

rapidly in constitution from place to place, map units should be so chosen as to associate rocks with common characteristics.

(*d*) If part of an igneous or sedimentary mass has been greatly altered, the limits between the greatly changed and the comparatively unchanged portions should be expressed cartographically, where the map scale permits.

(*e*) Where two or more adjacent formations are metamorphosed, they should, if practicable, be discriminated throughout the metamorphic area.

(*f*) The rule that petrographic features are the primary basis of discriminating metamorphic formations shall not be so rigorously applied as to demand establishing new formations within the same geologic body, merely because its mineral facies or texture varies from place to place.

Article 22.—The name by which a metamorphic formation is designated may consist of (1) the petrographic term alone, or (2) a geographic term and the petrographic term, if a geographic name is useful.

Remarks.—(*a*) The petrographic term should be, where not incompatible with precision, one of the generally accepted terms—for example, *phyllite, schist, gneiss, marble, hornfels, amphibolite,* or *eclogite.* This term may be modified by a descriptive term; as, *mica schist, granite gneiss.*

(*b*) Where no single petrographic term is appropriate, the word *formation* shall ordinarily be used instead of the petrographic term.

(*c*) Where a large mass is composed of diverse rocks of any class, or classes, and is characterized by highly complicated structure, the word *complex* may be used.

(*d*) A geographic name, used for a metamorphic formation, shall be subject to the same rules as govern names used for sedimentary formations.

SECTION V.—CORRELATION AND TIME CLASSIFICATION

Article 23.—Fundamental data of geologic history are (1) the local, provincial sequences of rocks; (2) chronologic equivalence of the rocks in the different provinces, as deduced from the fossil faunas and floras and from other data.

Remarks.—(*a*) Through correlation by faunas and floras, all the local rocks are referred to a standard time scale. In its beginning, this scale was purely stratigraphic, and the units were the systems recognized in specific regions. It has since been generally accepted, however, that, for purposes of discussion and correlation, it is useful to conceive these separate systems as the deposits formed during the separate time divisions called *periods,* and thus a standard time scale has been created. It is customary to speak of the *chronologic equivalence* of different rock units, though it is not possible actually to prove exact equivalence in time, and there is always inherent in such usage an element of assumption. Nevertheless, the concept of standard time units, based upon a standard stratigraphic scale, is a necessity for clear and orderly presentation of historical data.

(*b*) Correlation of nonfossiliferous rocks with the standard time scale is necessarily indirect, if possible at all. It must depend on some definite relation to fossiliferous rocks that can be referred to the general scale.

(*c*) Even in a small map area, there is need for correlation between exposures of the same minor unit, and between units of the map area and those of adjacent areas. Often these local correlations may be made without paleontologic data. With increase in size of the area considered, generally accompanied by a reduction in the scale of the map, the map units must be more inclusive and the correlations more general; there is less use for lithologic features and greater need for paleontologic criteria. Eventually, for the most inclusive maps, as state and national maps, the local units are negligible, and the standard, widespread units are of greatest importance. Correlation of these units must be based on paleontologic data.

Article 24.—The following divisions of geologic time are recognized:

(1) *Era*, the largest division of geologic time, consisting of several periods. Example, *Paleozoic era*.

(2) *Period*, the fundamental unit of the standard geologic time scale, the time during which a standard system of rocks was formed. Example, *Devonian period*.

(3) *Epoch*, a subdivision of a period. The term is applied primarily to a major subdivision, but it is likewise used for any subordinate unit except for the subdivisions of the Pleistocene epoch. Examples, *Early Devonian epoch*, and, for part of it, *Oriskany epoch*.

Remarks.—(*a*) The names applied to the eras are based on the concept of progressive change in the life of the earth, and end in the suffix *zoic*.

(*b*) The names applied to the periods are derived from the names of rock units in specific regions, mainly in western Europe—that is, the time included in the period is, theoretically, that time during which was being formed the specific rock unit from which the name came. Actually, the type region may contain only a part of the full sequence assigned, in general usage, to the particular system—for example, the Devonian of Devonshire, England—but it is customary to select other regions where the sequence is more nearly complete to supplement the type regions and to erect, thereby, a composite practical standard. Thus, the working concept is formed of the standard unit of time corresponding to the standard sequence of rocks. In these rocks occur fossils that serve as a means of referring other sequences of rocks to the standard time unit.

In general, the period is the smallest unit believed to be recognizable throughout the world—a fact indicated in the adoption everywhere of the names originally applied in Europe. By custom, certain epoch names are also widely used and imply a world-wide recognition—for example, the *Eocene epoch*. However, the modifications of correlation that inevitably follow increased knowledge, and the shifting of opinion among specialists, about the precise limits of even such broad divisions as periods, make it seem much more likely that no divisions subordinate in rank to periods can approximate the ideal of universal recognition.

(*c*) The names applied to the epochs corresponding to standard series are derived from those of the periods by using the words *Early*, *Medial*, and *Late;* or from the names of subordinate rock units. In names derived from the periods, as *Early Devonian*, both words are capitalized. In any other use, *early*, *medial*, and *late* are not capitalized.

(*d*) Adjective terms ending in *an*, derived from the names of subordinate rock units, such as *Niagaran* or *Claibornian*, may be used to indicate correlation or approximate position in the general time scale, provided that the geologic limits implied by the adjective shall be essentially those of the original unit. However, considerations of euphony may make it desirable to avoid the adjective form of some terms.

(*e*) Various terms have been proposed for the lesser subdivisions of geologic time. For example, the International Geological Congress has adopted, in addition to *era*, *period*, and *epoch*, the terms *subepoch*, *age*, and *phase*. These three have found little acceptance in America, for *epoch* and the somewhat indefinite term *time* have seemed to answer satisfactorily for all units subordinate to *period*.

(*f*) By long-continued custom in the United States, the time covered by a Pleistocene subdivision of formational rank is called a *stage*, and the time covered by a Pleistocene subdivision of member rank is called a *substage*. (See Article 2.)

(*g*) An explanation accompanying a map should indicate the names of the formations, together with their assignment to periods, and, wherever practicable, their more definite correlation, either by reference to established epochs or to early, medial, or late portions of the respective periods. The presence of erosion intervals and unconformities may be indicated in the explanation of the map.

Article 25.—In the classification of a formation, if paleontologic evidence is lacking or inconclusive, leaving doubt as to the period to which the formation belongs, it shall, in general, be referred to some one period, according to the preponderance of all available evidence, and the doubt as to the reference shall be indicated by a question mark, or by the word *probably* (or *possibly*). On map explanations, the doubt shall be indicated by dashing the bracket opposite the doubtful block.

Remarks.—(*a*) If the available paleontologic evidence is interpreted to show that a formation is transitional between two periods, its supposed transitional character may be indicated by a combination of period names—as *Cretaceous and Tertiary*—but it is usually desirable to avoid such a combination, even if an arbitrary classification is thereby made necessary. It is not to be denied that transitional units exist, but for practical purposes a doubt in classification is as well expressed by a queried assignment as by a combination of names.

(*b*) If the age of a formation is indeterminate within wide limits, the best possible assignment may be merely an indefinite reference by the prefix *post* or *pre*, used with the name of the unit nearest to it whose age assignment is definite. For example, a granite may be known merely to be pre-Cretaceous, or it may be known merely to be post-Cambrian.

Article 26.—The time intervals represented by unconformities shall not receive formal names. They should, in general, be referred to preceding or succeeding formations by the prefixes *pre* and *post*—for example, *pre-Moenkopi interval*, *post-Laramie interval*. Where such convenient names for time intervals as *Lipalian interval* and *Laramide revolution* are used, they shall have no part in formal stratigraphic nomenclature. Similarly, the naming of time intervals represented by cycles of erosion that are expressed in present-day land forms—for example, *Elk Valley erosion cycle*—is permissible, but such physiographic names, likewise, have no part in formal stratigraphic nomenclature.

Remarks.—It is undesirable to use the same geographic name for an erosion cycle or erosion surface and for a rock unit—for example, *Fremont erosion cycle* in Wyoming and *Fremont limestone* in Colorado—though such duplication may be useful if an erosion surface is continuous with the surface constructed from the deposits, so that both surface and deposits are of approximately the same age (see Article 18). It is particularly undesirable to duplicate in the same region, a geographic name for an erosion cycle and erosion surface and for a rock unit of totally different age—for example, *Jonesville cycle and erosion surface* and *Jonesville group*, both names derived from the Jonesville Hills.

PERMIAN ALGAL REEF IN SOUTH PARK, COLORADO[1]

While preparing the road log for the International Geological Congress Guide Book 19 (Excur. C.I.), T. S. Lovering discovered what he believes to be a reef of algal limestone.[2] Knowing the writer's inter-

[1] Published by permission of the director, United States Geological Survey.

[2] T. S. Lovering, *Intern. Geol. Congress, XVI Session, Guide Book 19* (1932), p. 112.

est in Paleozoic algae, Mr. Lovering very kindly showed him the deposit.

The reef is located about 15½ miles south-southeast of Fairplay, east of the Fairplay-Hartzel highway. It is composed of dolomitic limestone surrounded by red beds of Permian age. The reef is ap-

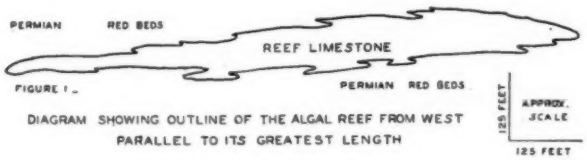

FIG. 1

proximately 1,100 feet long, 80 feet thick, and 300 feet wide. The outlines are not symmetrical but show irregular tongues of algal limestone interfingering with the red beds (Fig. 1 and Fig. 2).

The Permian red beds here consist mainly of fine-grained sandstone and sandy shales. A few layers and streaks of coarser material

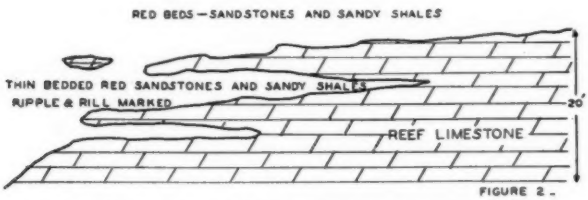
RED BEDS—SANDSTONES AND SANDY SHALES
THIN BEDDED RED SANDSTONES AND SANDY SHALES
RIPPLE & RILL MARKED
20'
REEF LIMESTONE
FIGURE 2 -
DIAGRAM SHOWING DETAIL OF RED BED-LIMESTONE CONTACT OF TOP OF REEF

FIG. 2

occur. All the deposits are somewhat micaceous. The bedding is thin and most of the surfaces are ripple marked. A few of the surfaces show rill marks and impressions of the *Rivularites* type very similar to *Rivularites permiensis*, which David White[3] described from the Hermit shale of the Grand Canyon of Arizona. These are commonly considered to be algal in origin. In some places red beds extend as far as 100 feet into the limestone mass nearly surrounded by tongues of limestone (Fig. 2).

The reef is composed of light gray, almost white, dolomitic limestone. On weathering the rock darkens somewhat, assuming a dark gray, tan, or cream tint. Some silicification has occurred, especially

[3] David White, *Carnegie Inst. of Washington Pub. 405* (1929), pp. 41–43, Pls. 6, 7, 8.

near the base, and thin layers, streaks, and irregular masses are partly or completely replaced by silica. The rock in the lower and central part of the reef is quite compact and close grained, but at the top and edges it tends to contain numerous small open spaces. This space seems to represent mostly original algal structure, but locally solution has enlarged some of the cavities and altered their shape. The limestone has a specific gravity of 2.74 and analysis by F. G. Hills, of the Experimental Plant of the Colorado School of Mines, shows 32.2 per cent CaO, 20.9 MgO, 0.7 Fe_2O_3, 3.2 insoluble matter (mainly fine sand grains), and 43 CO_2.

Stratigraphically the reef occurs high in the Permian series, which is at least 5,000 feet thick in South Park. The unconformable contact with the overlying Morrison (Jurassic) formation is about 75 feet stratigraphically above the top of the reef.

The algal limestone is more resistant to weathering than the surrounding red beds, hence the reef shows topographically as a small ridge or hill just west of the Dakota hogback.

The reef seems to have been built as a result of the activity of one species of the lime-secreting algae and represents the development of a large colony of the plants through a considerable interval of time. The masses of algae assumed a rounded growth form which is reflected in concentric structures in the limestone. In the mass of the reef perfectly shaped heads seldom occur on account of intergrowth, but some fairly well developed heads were observed at the top of the reef where examples as large as 10 inches in diameter occur.

A microscopic examination of thin sections of the rock shows that the organic structure has been partly destroyed by the crystallization of the dolomite, but numerous crumpled and broken threads, hollow tubes, and masses of cellular tissue occur. The writer hopes to be able to describe this and some other Carboniferous algae from central Colorado at a later date.

J. HARLAN JOHNSON

COLORADO SCHOOL OF MINES
GOLDEN, COLORADO
May 15, 1933

OVERTURNED BEDS IN ARBUCKLE MOUNTAINS, OKLAHOMA

A trip to the Arbuckle Mountains in April, this year, with Frank R. Clark, of Tulsa, resulted in some interesting observations.

Under the able guidance of John Fitts of Ada, the locality of an asphalt deposit, previously seen by A. I. Levorsen, in Sec. 29, T. 2 N.,

R. 6 E., 2 miles northwest of Franks, was visited. At this point asphalt occurs in a massive, extremely porous limestone and in an overlying bed of limestone conglomerate.

The limestone is probably upper Hunton (Devonian), and the conglomerate is part of the Holdenville (Pennsylvanian). The former, and apparently the latter, are highly tilted, with almost vertical dips.

Approximately 1,000 feet southwest of the asphalt deposit, in the north bank of Big Spring Creek, the base of the Hunton was found dipping about 10° from the vertical, *toward the southwest, and overlain, with conformable dip, by Sylvan shale*, indicating overturning. About 40 feet of Sylvan is visible at this point, though the lateral extent along the strike was not determined.

In the southwest slope of the valley, no rocks are exposed for a distance of 500 feet, and the first beds to be seen belong to the Simpson formation, dipping normally northeast at angles ranging from 10° to 20°. The fault shown on Decker's[1] map intervenes between the Simpson and Hunton, but contrary to that mapping, some Sylvan also is present. Part of the Simpson, and all the Viola, are cut out by the fault. Several cross faults, at right angles to the strike of the beds, cut the Simpson and Hunton, with horizontal displacement ranging from 10 to 50 feet.

Later, in company with C. W. Tomlinson, of Ardmore, numerous exposures along the north limb of the Arbuckle anticline, south of Washita River, were visited. Tomlinson called attention to the fact that most of the folds in the Arbuckle Mountains are asymmetrical, with the north limb the steeper. This is obvious in the Arbuckle anticline, and proved to be true in all folds seen.

In Sec. 30, T. 1 S., R. 2 E., about halfway between Turner's Falls and the Washita River bridge, on Highway 77, a syncline may be seen in beds of Viola limestone, exposed in a high cliff on the right (east) bank of Honey Creek. Beds present in the southwest limb of this syncline are practically vertical in the top of the cliff, but near the base may be seen to dip south at angles ranging from 35° to 45°, indicating that the anticline of which they form the northeast limb is overturned in that direction.

Northeastward, the beds may be seen to rise from the axis of the syncline, toward another anticline, at an angle of about 30°. The syncline is asymmetrical, and one of the adjacent anticlines has an overturned northeast limb, while the other has a relatively gentle southwest limb.

[1] Chas. E. Decker, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55* (1931).

Southeastward from the mouth of Honey Creek toward Dougherty, many excellent exposures of all beds from Caney to Simpson may be seen, either along the road, or a short distance up the streams which cross it. Without exception, these exposures exhibit dips overturned from a few degrees to as many as 45° (135° from normal), and Woodford may be found resting on Sycamore, Sylvan on Hunton, Simpson on Viola, and the like.

One exceptionally interesting outcrop was found in a small creek which enters Washita River opposite Dougherty, and in which the Ardmore Boy Scout Camp is located. Sylvan shale is exposed in the right (east) bank of the creek, about ¼ mile upstream from the main road. Here, in an exposure 2 feet high and 20 long, the Sylvan dips at angles ranging from 103° to 111°, overturned toward the south. Within the exposures are three faults, a syncline and two anticlines, the latter with axes inclined southwest, and asymmetrical to overturned toward the northeast. The faults dip southwest, one at 44°, another at 49°, and the third more nearly vertical.

An unsuccessful attempt was made to locate the plane of the large fault shown on Decker's map, in the hope of measuring its dip. The trace is marked by changes in strike, dip, and formation, and apparently by the presence of large springs, but the plane could not be found in the general vicinity of Turner's Falls, Price's Falls, the Boy Scout camp, or for a dozen miles southeast.

The Dougherty anticline, on the northeast, across the Washita syncline, is likewise asymmetrical, and slightly overturned northeast. At the south end of the Viola exposure in the A. T. & S. F. R. R. cut, in Sec. 21, T. 1 S., R. 2 E., the beds dip 45° SW., and this angle prevails for about 600 feet north, at which point the axis is passed, and an overturn of 108° may be noted. Thence northward for a short distance, dips are vertical, and gradually flatten to about 30° NE. at the north end of the exposure, ½ mile or so from the axis.

It is not to be presumed that a new discovery has been made in these overturned beds. In fact, students of geology from the University of Oklahoma have been seeing them year after year. So far as can be determined, however, Arbuckle literature is surprisingly silent on overturned beds and overturned folds, though cross section *B–B* on Decker's map does suggest this condition, in a compressed syncline northwest of Honey Creek.

Reeds[2] in discussing the faulted nature of the Tishomingo and Arbuckle anticlines, states: "The axial planes of these folds are in-

[2] Chester A. Reeds, "A Report on the Geological and Mineral Resources of the Arbuckle Mountains, Oklahoma," *Oklahoma Geol. Survey Bull. 3* (1910), p. 48.

clined to the south." He further states: "If it were possible to measure the length of the greatly faulted limbs of the truncated complex folds, this would be a factor in determining the presence of overturned folds." Apparently no one has hitherto specifically described, or called attention to, the overturned beds in the faulted north limb of the Arbuckle anticline.

These overturned beds and overturned folds are strong evidence to support a hypothesis already propounded by the writer,[3] namely, that overthrusting has played an important part in producing the present form of the Arbuckle Mountains. The small exposure of Sylvan shale in the creek opposite Dougherty may be taken as a miniature representation of Arbuckle structure, and shows the presence of overturned folds and thrust faults.

Gratitude is hereby expressed to Clark, Fitts, and Tomlinson, for their assistance in searching out and interpreting these revealing data.

ROBERT H. DOTT

TULSA, OKLAHOMA
May 20, 1933

PERMEABILITY, ITS MEASUREMENT AND VALUE

CORRECTION

In the article, "Permeability, Its Measurement and Value," by Charles Merrick Nevin, in the *Bulletin*, Vol. 16, No. 4 (April, 1932), p. 382, the first line of the last paragraph should read: "*Example 1.*—Given a sample *2* inches high and *2* inches in diameter."

[3] Robert H. Dott, "Pennsylvanian Paleogeography," *Oklahoma Geol. Survey Bull. 40–J* (1927), p. 17; *ibid.*, *Bull. 40*, Vol. 1 (1928), p. 63; "Structural History of Arbuckle Mountains, Oklahoma, in Pennsylvanian Time," paper read before the Association at the Houston meeting, March 24, 1933.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 7 (JULY, 1933), PP. 869-871

DISCUSSION

REVIEW OF TERTIARY STRATIGRAPHY OF LOUISIANA

United States Geological Survey
Washington, D.C., May 16, 1933

Mr. A. F. Crider
1212 City Bank Building
Shreveport, Louisiana
Dear Mr. Crider:

I appreciate your forwarding me a copy of your discussion of Doctor Howe's paper. You have given a fine statement of the situation relating to Sabine vs. Wilcox. As I explained in my discussion at the Houston meeting, the use of the term Wilcox has been so general for many years that such usage should apparently outweigh the matter of type localities and priority. My opinion is that much confusion in nomenclature would be caused by a shift from Wilcox to Sabine at this time, and that this confusion can be avoided by adhering to Wilcox.

For your information, I am enclosing a copy of a portion of my memorandum of March 15, 1933, in reply to Doctor Howe's letter of March 8, which deals with the matter of the use of Sabine and Wilcox.

Very truly yours,

(Sgd.) HUGH D. MISER, *chairman*
Committee on Geologic Names

cc to L. C. Snider, C. L. Moody, Ira Cram, H. V. Howe, Alex. Deussen

---

United States Geological Survey
Washington, D.C., March 15, 1933

MEMO. FOR DIRECTOR, IN RE LETTER OF H. V. HOWE,
DATED MARCH 8, 1933

In 1890 Dumble and Penrose introduced the name "Timber Belt or *Sabine River beds*" for the deposits in Texas between the "Basal or Wills Point clays" (=Midway of present nomenclature) and "Fayette beds" above. As thus defined, "*Sabine River beds*" included the Wilcox group and most of the overlying Claiborne group. But in subsequent Texas reports the name *Sabine River* was dropped and "Lignitic" and "Timber Belt division" were employed instead.

Early in 1904 the Committee had occasion to consider the names to be used in a report by A. C. Veatch on *northern Louisiana and southern Arkansas*, and approved the name *Sabine formation* for the deposits overlying the Midway formation and underlying the deposits called Claiborne in northwestern Louisiana and southwestern Arkansas.

Early in 1905, and before the publication of Mr. Veatch's report, the Committee had occasion to consider the names to be used in other reports by Sur-

vey authors on Mississippi. Because of the uncertainty that then existed as to the equivalency of the "Lignitic" deposits of northwestern Louisiana with the belt of similar deposits in eastern Mississippi and western Alabama, and of the equivalency of the deposits called Claiborne in northwestern Louisiana with the typical Claiborne of Alabama, the authors and the Committee felt that a name should be selected for the eastern or typical belt of "Lignitic" that would be acceptable to the State Geologist of Alabama and Mississippi geologists. After correspondence, the name *Wilcox*, from the county in Alabama over which the deposits are widespread, seemed to be the most appropriate and acceptable name for the eastern belt of typical "Lignitic," as that term had come to be restricted to post-Midway and pre-Claiborne deposits, and it was, accordingly, adopted. At the time Wilcox was adopted the Committee stipulated that *Sabine formation* could be used for the western belt of "Lignitic" provided Mr. Veatch did not care to make the definite correlation with the eastern belt that would be implied by the use of the name Wilcox in northwestern Louisiana and southwestern Arkansas. He preferred to use *Sabine formation*.

Between 1905 and 1910, considerable intensive work was done by other United States Geological Survey geologists in Louisiana and eastern Texas, and in 1910 Messrs. Vaughan and Deussen expressed the opinion that the Sabine formation of Veatch was the same as the Wilcox formation of Mississippi and Alabama, and that one name should be applied to the deposits. The Committee at that time decided that "Sabine River beds" and "Sabine" formation should be abandoned for Survey publications, and that the name *Wilcox formation* should be used in Louisiana and Texas as well as in the other Gulf States.

Since that time the eastern belt of "Lignitic" (Wilcox) deposits has been traced northward and mapped in western Tennessee and Kentucky and southern Illinois, and eastward into Georgia, while the western belt has been mapped over large areas in Texas, northwestern Louisiana, and southern Arkansas. The name *Wilcox* has, therefore, become firmly entrenched in the literature, having been used in nearly 100 reports on Alabama, Georgia, Mississippi, Tennessee, Kentucky, Illinois, Arkansas, Louisiana, Texas, and Mexico, while *Sabine* has been used in only 9 reports (the last in 1920), and has been adopted (1920) by the Canadians (and used in 5 reports) for a Cambrian formation in British Columbia.

The thickness of the Wilcox of Alabama is 609 feet; the thickness in Mississippi is 1,435 feet; in western Tennessee 600 ± feet; Veatch gave the thickness in Louisiana as 1,000 feet; the thickness in eastern Texas has been given as 950 to 2,450 feet. Very few if any geologic units are *fully* represented at their type localities, and that fact should not be a bar to the continued use of Wilcox instead of Sabine.

It was regrettable that the term "Wilcox sand" was in 1921 applied to an Ordovician sand encountered in wells in Oklahoma. Because of this conflict the United States Geological Survey, and Oklahoma geologists generally, quote the name, it having been used in quotation marks when it was introduced into the literature. . . .

(Sgd.) H. D. MISER, *chairman*
Committee on Geologic Names

Houston, Texas
May 22, 1933

Mr. Hugh D. Miser,
Chairman, Committee on Geologic Names,
Department of the Interior,
United States Geological Survey, Washington, D. C.

Dear Mr. Miser:

I wish to acknowledge receipt of copy of your letter under date of May 16th addressed to Mr. A. F. Crider of Shreveport, Louisiana, in regard to the question raised by Dr. H. V. Howe in his paper presented at the Houston Meeting, suggesting the abandonment of the name Wilcox in favor of Sabine, because of better type locality and priority in the use of the name Sabine as compared with Wilcox.

Since the time that Dr. Howe raised this question I have given considerable thought to the matter, and I have noted with interest the recent discussion by Mr. Crider.

After due consideration it occurs to me that it would be unwise to abandon the use of the name Wilcox for the reason suggested by Dr. Howe.

The name Wilcox, as pointed out by you, has become so firmly entrenched in the literature since 1910, that it seems to me that it is undesirable to introduce a new name at this time, and to make for the confusion incident thereto.

For this reason I would favor the continuance of the use of the name Wilcox.

In this connection, I have again read over my discussion of the use of the name Wilcox in the report which I published in 1914, Water Supply Paper No. 335, United States Geological Survey, which I wish to quote herewith.

> The formation here considered is called the Wilcox, after Wilcox County in Alabama, where it is characteristically exposed. It was first recognized and described in 1894 by Harris, who gave it the name "Lignitic." The same group of beds was called "Chickasaw" by Dall in 1896, "Sabine" by Veatch in 1906, and Wilcox by Crider in 1906. "Lignitic" is a lithologic and not a geologic name and therefore is not in accord with the rules of geologic nomenclature. "Chickasaw" was originally proposed by Hilgard as an equivalent for the beds he called the "Northern Lignitic," in which he included beds belonging to the Wilcox, Claiborne, and Jackson; Dall used the term later to apply to beds here recognized as Wilcox. "Sabine River beds" was applied by Penrose in 1890 to deposits that included a portion of the Claiborne, and his use of this term would have precedence over Veatch's use of "Sabine." Wilcox is thus the only name to which there are no objections, and it is therefore adopted in this report as the proper designation for this division of the Eocene.

It seems to me that the reasons given for the use of the name Wilcox at that time in preference to Sabine are still pertinent, notwithstanding the points raised by Mr. Howe.

With best wishes, I am,

Yours very sincerely,
(Sgd.) ALEXANDER DEUSSEN

cc A. F. Crider, L. C. Snider, C. L. Moody, Ira Cram, H. V. Howe

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 7 (JULY, 1933), PP. 872-873

REVIEWS AND NEW PUBLICATIONS

RECENT PUBLICATIONS

AUSTRALIA

Geological Map of the Commonwealth of Australia, by T. W. Edgeworth David. Based chiefly on maps published by the geological surveys of the states and by the Commonwealth Government, and on information supplied by the geological survey staffs, and by colleagues at the universities and elsewhere. Drawn and printed at Department of Lands, Sydney, N. S. W., 1931, for Commonwealth Council for Scientific and Industrial Research. Scale, 1:2,990,000. Four sheets each, approx. 42 × 34 inches. In colors. With geologic sections.

Explanatory Notes to Accompany a New Geological Map of the Commonwealth of Australia, by T. W. Edgeworth David. Published by the Commonwealth Council for Scientific and Industrial Research, and issued by permission of Edward Arnold and Company, 41–43 Maddox Street, London, W. 1 (1932). 177 pp., 10 figs., 11 tables. 10 × 6¼ inches. Cloth.

CALIFORNIA

"Some of Alpheus Hyatt's Unfigured Types from the Jurassic of California," by C. H. Crickmay. *U. S. Geol. Survey Prof. Paper 175-B* (1933). Pp. i–ii, 51–64, Pls. 14–18. Price, $0.05.

COLORADO

"Geology and Oil and Gas Prospects in Part of Eastern Colorado," by C. H. Dane and W. G. Pierce. *U. S. Geol. Survey Press Notice 72215* (June 8, 1933).

FLORIDA

The Florida State Geological Survey, Herman Gunter, state geologist, Tallahassee, has issued the following reports, each 6 × 9 inches, paper covers.

"Miocene Pelecypods of the Choctawhatchee Formation of Florida," by W. C. Mansfield. *Bull. 8* (1932). 240 pp., 3 figs., 34 pls.

"The Foraminifera of the Upper, Middle, and Part of the Lower Miocene of Florida," by Joseph A. Cushman and Gerald M. Ponton. *Bull. 9* (1932). 147 pp., 1 fig., 17 pls., 2 tables.

"Miocene Vertebrates from Florida," by George Gaylord Simpson, Albert Elmer Wood, and Edwin H. Colbert. *Bull. 10* (1932). 58 pp., 30 figs.

"Ground Water Investigations in Florida," by V. T. Stringfield. *Bull. 11* (1933). 33 pp.

"Twenty-Third-Twenty-Fourth Annual Report, 1930–1932," by Herman Gunter. Among other reports, contains the following. "Notes on the Geology and the Occurrence of Some Diatomaceous-Earth Deposits of Florida," by Herman Gunter and Gerald M. Ponton, pp. 57–64, Figs. 3–5; "Diatoms of the Florida Peat Deposits," by G. Dallas Hanna, pp. 65–119, Pls. 1–11:

"Ground Water Resources of Sarasota County, Florida," by V. T. Stringfield, pp. 121–94, Figs. 5–23; "Exploration of Artesian Wells in Sarasota County, Florida," by V. T. Stringfield, pp. 195–227.

GENERAL

Oil and Petroleum Year Book, 1933, by Walter E. Skinner. Twenty-fourth annual edition. International listing of oil companies, including officials, properties, operations, financial status, et cetera. Statistics on world's production of crude. Technical glossary. 446 pp. Published by Walter E. Skinner, 15 Dowgate Hill, Cannon Street, London, E. C. 4. Price, 7 *s.* 6 *d.*; abroad, 8 *s.* 6 *d.*

Igneous Rocks and the Depths of the Earth, by Reginald Aldworth Daly. Contains some revised chapters of *Igneous Rocks and Their Origin* (1914). McGraw-Hill Book Company, Inc., New York (1933). 598 pp., 190 figs. 6 × 9 inches. Cloth. Price, $5.00.

Historical Geology, by Raymond C. Moore. An introduction to earth history with special reference to North America. McGraw-Hill Book Company, Inc., New York (1933). 600 pp., 400 illus. 6 × 9 inches. Cloth. Price, $4.00.

GEOPHYSICS

"La géologie profonde de la France d'après le nouveau réseau magnétique et les mesures de la pesanteur" (Subsurface Geology of France, According to New Magnetic and Gravimetric Surveys), by Jean Jung. From *Annales de l'Institut du Globe de l'Universitê de Paris*, Vol. 2 (1933). 51 pp., 30 figs., 4 pls.

GERMANY

"Die württembergischen Ölschiefervorkommen und die Frage ihrer Bedeutung" (The Wurtemberg Oil Shale Development and its Significance), by Rudolf Wager. *Kali, Verwandte Salze, und Erdöl* (Wilhelm Knapp, Halle, Saale, Germany), Heft 10 (May 15, 1933), pp. 122–24; 2 figs.

MONTANA

Recent Gas Developments in North Central United States, by C. E. Erdmann and J. R. Schwabrow. *U. S. Geol. Survey map* (1933). Gas fields in Montana, northern Wyoming, the Dakotas, Minnesota, and adjacent Canada. Scale, 1 inch = 40 miles. Washington, D. C. Free.

The Bowdoin Gas Field, Montana, by C. E. Erdmann and J. R. Schwabrow. *U. S. Geol. Survey map* (1933). Structure, stratigraphy, development. Scale 1 inch = 1 mile. Washington, D. C. Free.

UTAH

"Geology and Oil Possibilities of the Moab District, Grand and Saline Counties, Utah," by A. A. Baker. *U. S. Geol. Survey Bull. 841* (1933). v + 95 pp., 11 pls., 3 figs. Price, $0.50.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 7 (JULY, 1933), P. 874

THE ASSOCIATION ROUND TABLE

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

FRANK R. CLARK, *chairman*, Mid-Kansas Oil and Gas Company, Tulsa, Oklahoma
WILLIAM B. HEROY, *secretary*, Sinclair Exploration Company, New York, N. Y.
FREDERIC H. LAHEE, Sun Oil Company, Dallas, Texas
GEORGE SAWTELLE, Kirby Petroleum Company, Houston, Texas
L. C. SNIDER, H. L. Doherty and Company, New York, N. Y.

GENERAL BUSINESS COMMITTEE

ARTHUR A. BAKER (1934)
ALBERT L. BEEKLY (1934)
FRANK R. CLARK (1935)
H. E. CRUM (1935)
JOSEPH A. DAWSON (1935)
C. E. DOBBIN (1935)
JAMES TERRY DUCE (1935)
WALTER A. ENGLISH (1934)
H. B. FUQUA (1935)
M. W. GRIMM (1935)
S. A. GROGAN (1935)
WILLIAM B. HEROY (1934)
JOHN F. HOSTERMAN (1935)
EDGAR KRAUS (1935)
FREDERIC H. LAHEE (1934)
ROLAND W. LAUGHLIN (1935)
THEODORE A. LINK (1935)
R. T. LYONS (1935)
ROY G. MEAD (1935)
A. F. MORRIS (1935)
WILLIAM M. NICHOLLS (1934)
PHILIP E. NOLAN (1935)
L. W. ORYNSKI (1934)
CLARENCE F. OSBORNE (1935)
E. E. ROSAIRE (1934)
GEORGE SAWTELLE (1934)
L. C. SNIDER (1934)
J. D. THOMPSON (1934)
WALLACE C. THOMPSON (1935)
PAUL WEAVER (1935)
G. H. WESTBY (1934)
E. A. WYMAN (1935)

RESEARCH COMMITTEE

DONALD C. BARTON (1936), *chairman*, Petroleum Building, Houston, Texas
M. G. CHENEY (1934), *vice-chairman*, Coleman, Texas

K. C HEALD (1934)
F. H. LAHEE (1934)
H. A. LEY (1934)
R. C. MOORE (1934)
F. B. PLUMMER (1934)
C. E. DOBBIN (1935)
A. I. LEVORSEN (1935)
ALEX. W. MCCOY (1935)
C. V. MILLIKAN (1935)
L. C. SNIDER (1935)
L. C. UREN (1935)
HAROLD W. HOOTS (1936)
R. S. KNAPPEN (1936)
W. C. SPOONER (1936)
PARKER D. TRASK (1936)

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

R. S. KNAPPEN (1934)

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

M. G. CHENEY, *chairman*, Coleman, Texas

JOHN G. BARTRAM
IRA H. CRAM
ALEXANDER DEUSSEN
B. F. HAKE
G. D. HANNA
A. I. LEVORSEN
C. L. MOODY
R. C. MOORE
ED. W. OWEN

TRUSTEES OF REVOLVING PUBLICATION FUND

E. DEGOLYER (1934) FRANK R. CLARK (1935) CHARLES H. ROW (1936)

TRUSTEES OF RESEARCH FUND

W. E. WRATHER (1934) ALEX. W. MCCOY (1935) ROBERT H. DOTT (1936)

FINANCE COMMITTEE

E. DEGOLYER (1934) W. E. WRATHER (1935) JOSEPH E. POGUE (1936)

COMMITTEE ON APPLICATIONS OF GEOLOGY

F. H. LAHEE, *chairman*, Box 2880, Dallas, Texas

WILLIAM H. ATKINSON
DONALD C. BARTON
FORD BRADISH
ARTHUR E. BRAINERD
H. A. BUEHLER
HAL P. BYBEE
W. F. CHISHOLM
HERSCHEL H. COOPER
CAREY CRONEIS
MARVIN LEE
S. E. SLIPPER
E. K. SOPER
LUTHER H. WHITE
R. B. WHITEHEAD

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 7 (JULY, 1933), PP. 875-876

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

RICHARD E. KOCH, De Bataafsche Petroleum Maatschappij, is at Tjepoe, Java, D. E. I., for a few months.

GERALD A. WARING, of Washington, D. C., has completed his report for the United States Geological Survey on "The Core-Drill Prospecting for Coal in the Matanuska Valley, Alaska." Other press releases on Alaskan investigations are being prepared.

JOHN L. RICH, of the geological faculty of the University of Cincinnati, Ohio, has returned to Ottawa, Kansas, to continue consulting work during the summer. He was in New York State during part of June.

FRED BRASTED, JR., geologist for the Stanolind Oil and Gas Company, has been transferred to Casper, Wyoming, from Shawnee, Oklahoma.

ALLEN J. CHILDERHOSE, geologist for The Texas Company, Calgary, Alberta, Canada, may now be addressed at the Cut Bank Hotel, Cut Bank, Montana.

B. G. MARTIN, formerly of Healdton, Oklahoma, has been employed by the Gulf Production Company in the geological department, and has headquarters at Crane, Texas. His address is Box 399.

H. M. FRITTS, field geologist for the Shell Petroleum Corporation, and formerly at San Angelo, Texas, has been transferred to Houston, Texas.

GEORGE W. SCHNEIDER, division geologist for The Texas Company, at Shreveport, Louisiana, and Miss KATHERINE WATSON, of Tulsa, Oklahoma, were married at Tulsa, May 15. Schneider is president of the Shreveport Geological Society.

F. E. WELLINGS, geologist for the Iraq Petroleum Company, Ltd., and formerly of Kirkuk, Iraq, is now at Haifa, Palestine. His address is Box 309.

The Geological Society of Chicago held its last spring meeting on May 18. The speakers were THEO. A. LINK, Imperial Oil Company, and C. A. HEILAND, Colorado School of Mines, whose subjects respectively were the exhibits of Petroleum Geology and of Geophysical Methods at A Century of Progress Exposition at Chicago.

CHARLES F. BASSETT has changed his address from the University of Michigan, at Ann Arbor, to Hinckley, Illinois.

ELMER H. FINCH, formerly of San Antonio, Texas, is now located at the Auditorium Hotel, Houston, Texas.

E. W. ANDRAU, geologist for the Shell Petroleum Corporation, at Houston, Texas, is now at The Hague, Holland, and may be addressed in care of the Bataafsche Petr. Mij.

WALT M. SMALL is chief geologist for the European Gas and Electric Company, of New York, London and Vienna. His present address is Am Heumarkt 10, Vienna III, Austria.

M. B. TUCKER, formerly of Box 117, Marshall, Oklahoma, may now be addressed at 5340 Neosho Street, St. Louis, Missouri.

S. W. HOLMES, formerly of Box 312, Shawnee, Oklahoma, is now located at Box 477, Capitol Hill Station, Oklahoma City, Oklahoma.

W. I. ROBINSON, formerly of Milwaukee, Wisconsin, is now at Portland, Michigan.

VIRGIL E. BARNES has changed his address from 591 Ohio Avenue, Chehalis, Washington, to 1815 Avenue I, Galveston, Texas.

MARCEL E. TOUWAIDE, formerly petroleum engineer for the Bataafsche Petroleum Mij. in the Dutch East Indies, and for the Syndicat des Petroles in Morocco, is the author of a detailed study on coring methods entitled "L'échantillonnage dans les sondages modernes" (Sampling in Modern Drill Holes) now in course of publication in the *Revue Universelle des Mines*, published in Liége, Belgium (issues of May 15, June 1, July 1 and 15, and August 1).

P. H. REAGAN, mining engineer of Tucson, Arizona, since returning from several years of mining experience in Chile, has been engaged in special post-graduate work in geology at the University of Arizona, where he received the professional degree of engineer of mines this spring. Reagan is spending the summer in California, where he may be addressed at Box 272, Berkeley, California.

C. H. BIRDSEYE, of the Map Information Office, United States Geological Survey, Washington, D.C., has prepared a complete card catalog on aerial maps made in the United States. This catalog covers surveys made by all private companies in addition to surveys made by Army and Navy aviators. To avoid competition with private aerial mapping companies, the Government will not supply maps made by the Army or Navy to private individuals. Those interested in securing aerial maps of any particular area are invited to correspond with Col. Birdseye regarding the areas involved. He will promptly advise whether the area has been mapped by any commercial company, and give the name of the company and date of survey. By correspondence with Col. Birdseye, one may quickly determine whether an area has been mapped, and will be placed in contact with the company which is prepared to supply a map of the region.

GILBERT W. NOBLE has changed his address from Box 200, Clarksburg, West Virginia, to 6917 Princeton Avenue, St. Louis, Missouri.